A Short History of Nearly Everything Study Guide

A Short History of Nearly Everything by Bill Bryson

BOOKRAGS

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Plot Summary

For people over 30 years of age, science has changed a great deal since they were in school. New scientific theories, developments and discoveries abound that adults may be interested in learning about. However, how would one go about learning these things in an easy, simple way? Author Bill Bryson readily admits that he found science textbooks boring as a child, and his book, *A Short History of Nearly Everything,* is the successful result of his effort to produce a concise, readable, entertaining summary of current scientific thinking, for adults.

Each section within the book deals with one sphere of inquiry, such as outer space, the Earth, and living things. Each chapter explores a specific question such as "How did the Universe start?" or "What are supernovae and why are they important?" This is usually this is done by tracing the development of a thought or theory on a particular issue from its origin to the present. Along the way, Bryson illuminates the interesting and inspirational lives of key scientists and researchers.

Part 1 focuses on our universe and mankind's place in it. The first chapter details the Big Bang Theory, which suggests that the universe was formed in just a few brief moments. Two young astronomers, Arno Penzias and Robert Wilson, detected visible matter believed to be remnants of the Big Bang, and thus inadvertently discovered the evidence of this now-popular theory. Although they shared a Nobel Prize for their work, neither man realized the significance of their discovery until they read about it in *The New York Times*.

The size, shape, weight and orbit of the Earth are the focus of Part 2. In these chapters, Bryson profiles important geologists such as Henry Cavendish, who, in 1797, accurately measured the weight of the Earth using an apparatus so delicate that he had to peer at it with a telescope through a keyhole from an adjoining room. These chapters also detail Marie Curie's work with uranium, and explain why it was a European - not an American - who first described a dinosaur.

In Part 3, Bryson presents the theory of relativity and quantum physics as comprehensibly as possible. This section illuminates the flexible fabric of spacetime and the incredible amount of energy locked inside every molecule. It also attempts to explain the complex, static sub-atomic world, where nothing exists until it is observed, electrons travel from one spot to another without going through the intervening space, the universe is composed primarily of solid nothing, and particles travel faster than light.

The frightening revelations in Part 4 outline the dangers the Earth faces every day. These include being hit by one of the millions of meteors that cross the Earth's path two or three times per week; the potential eruption of the supervolcano at Yellowstone; a type of earthquake that can occur anywhere, any time; the ever-present and growing threat of global warming; and the history of ice ages and the possibility of their reoccurrence.

The final section deals with the topic of life on Earth. Life is amazingly abundant, and inexplicably lacking in diversity. Every living thing on Earth uses the same blueprint for life, suggesting a common ancestor somewhere in the dim, distant past. Bryson concludes by pointing out that humans are very lucky to be here. Over 90 percent of species that have lived on Earth since the dawn of time have become extinct - some by natural processes and others by way of mankind's ignorance.

Part 1, Chapter 1

Part 1, Chapter 1 Summary and Analysis

Protons are so small that the dot in a printed letter *i* contains 5,000 million of them. The Big Bang, which is believed to be the origin of the universe, occurred when all existing matter was squeezed into a dot smaller than one proton. This space, so tiny it has no dimensions at all, is called a singularity. It's meaningless to discuss time and space in relation to singularities, for time didn't exist prior to the Big Bang, and neither did space.

In a single blinding pulse that lasted less than a minute, the universe expanded a million billion miles wide, and is still growing. Although there is some disagreement as to when this occurred, the general consensus among cosmologists is approximately 13.7 billion years ago. Georges Lemaitre, a Belgian priest, first proposed the Big Bang Theory in the 1920s, but it didn't really catch on until 1965. When it finally did, the discovery of evidence supporting the theory was completely accidental.

Arno Penzias and Robert Wilson were two young American astronomers experimenting with a large Bell Laboratories communications antenna in Holmdel, New Jersey in 1965. They were troubled by a persistent background noise that made their work impossible. For an entire year they tried to eliminate the background noise that seemed to be coming from every point in the sky, every day of the year. The two scientists tried everything, from laboriously scraping bird droppings off the antenna to sealing all the joints with duct tape. Nothing worked.

Finally, they went for help, contacting a team of scientists led by Robert Dicke at nearby Princeton University. The Princeton researchers were trying to prove an idea first suggested in the 1940s by a Russian astrophysicist. They believed that if one looked deeply enough into space one would find background radiation left from the Big Bang, in the form of microwaves. The Princeton team explained that what Penzias and Wilson were actually seeing was the visible part of the first photons, left over from the Big Bang. Despite the fact that the two young astronomers had no idea what they'd found and were not able to describe it or interpret it, they won the Nobel Prize for physics in 1978. The Princeton researchers received no recognition or compensation for their contribution to the discovery.

No one is exactly sure what caused the Big Bang. It might have been the result of an earlier, collapsing universe. Other scientists suggest false vacuums or a scalar field that introduced instability into nothingness caused it. Still others believe that the universe is part of many larger universes, some in other dimensions. They theorize that Big Bangs are going on all the time; or, perhaps space and time took on another form prior to the Big Bang.

If the universe had formed just a bit differently, mankind wouldn't be here at all. If gravity were slightly strongeror if the expansion had been slower or faster, there would not be enough stable elements to create the Earth, much less human beings. It's tempting to consider the universe as a custom-made environment to suit humankind's requirements for life, but as Alan Guth of Massachusetts Institute of Technology (MIT) points out, no one knows how many failed attempts to create such a universe there were. British astronomer Martin Rees believes that there may be an infinite number of universes with different attributes and that humans simply live in one that suits their needs. These views suggest that the cosmos is far more complex and wonderful than anyone can imagine.

As it is, in a single instant, a universe of at least 100 billion light-years wide (and some say infinite) was created, complete with stars, planets and galaxies. Where is the center of the universe? No one will ever know. According to Einstein's theories, the nature of space is that it curves. Imagine an ant walking on the surface of a tennis ball. Eventually, if the ant keeps walking, it will return to the region where it started. Space curves in just such a way.

Each chapter in this book deals with one area of scientific inquiry. Usually, each chapter answers one question, such as the one posed in this chapter, "Where did the Universe come from?" In general, Bryson traces the development of modern scientific knowledge on the topic in a chronological fashion, without flashbacks. He takes pains to include competing scientific theories and sometimes includes colorful or eccentric scientific personalities for added interest, despite the weakness of their theories.

Part 1, Chapter 2

Part 1, Chapter 2 Summary and Analysis

Radio telescopes used by astronomers today are so sensitive that if someone were to light a match on the moon, scientists on Earth could see the flare. According to Carl Sagan, the total energy collected by all the radio telescopes since 1951 is less than that generated by a single snowflake striking the ground. Despite this amazing accuracy, until 1978 no one noticed that Pluto has a moon. Actually, Pluto's moon is the biggest moon in the Solar System relative to the size of its respective planet. This fact proved to be quite a blow to Pluto's status as the ninth planet.

One reason it took so long to find Pluto's moon is that astronomers, like the rest of us, find what they are looking for. They don't scan the skies at random. They point their telescopes to the far reaches of the universe, searching for quasars or black holes, or to study distant galaxies. The only network of telescopes that randomly scans the skies is operated by the military. In 1978, James Christy was operating one such telescope in Flagstaff, Arizona, when he noticed a blurry, indistinct body next to Pluto.

Pluto itself was discovered in 1930, largely due to Percival Lowell. A scion of one of the oldest and wealthiest Boston families, he endowed the Lowell Observatory. Lowell was convinced that there was a fifth gas giant planet in the solar system, beyond Neptune. Unfortunately, this belief was based on wholly erroneous calculations of permutations in the orbits of Neptune and Uranus. Thirteen years after Lowell's death, the observatory hired a young man named Clyde Tombaugh to try to find the ninth planet. Tombaugh had no formal training in astronomy, but he was diligent, patient and motivated. Within a year, he had discovered Pluto, a tiny, icy planet. A few scientists still believe that there is a very large undiscovered planet or unformed star beyond Pluto.

Pluto, the first planet discovered by an American, was named partly in honor of Lowell. Still, many scientists question if Pluto should be considered a planet. They think it's just one of the larger comets in the Kuiper Belt. Some of their arguments are based on the fact that Pluto is tiny(less than half the size of the lower 48 states in the U.S. Its orbit varies erratically, to the point that scientists cannot predict Pluto's position with any accuracy. The plane of orbit is tilted 17 degrees away from the rest of the solar system. Throughout most of the 1980s and 1990s, Neptune was actually the planet furthest away, because Pluto's erratic orbit led it closer to the sun. The matter is closed, however. In February of 1999, the International Astronomical Union ruled Pluto a planet.

Even if Pluto is a planet, it is certainly an oddity. It is less than ? of one percent as massive as the Earth, which is itself a relatively small planet. With Pluto, the solar system consists of four rocky inner planets, four gas giant outer planets, and one tiny ice-ball planet. Several of the 600 identified comets in the Kuiper Belt, called Plutinos, approach Pluto in size. It's probably only a matter of time until a Plutino larger than Pluto is discovered. Still, it's a wonder that Pluto was discovered at all. These tiny lumps of ice reflect light about as well as lumps of charcoal, and they're four billion miles away.

Space is enormous(so huge that models are never made to scale. If the Earth were reduced to the size of a pea, Jupiter would be 1000 feet away. Pluto would be the size of a bacterium, 1.5 miles away. The nearest star, Proxima Centauri, would be 10,000 miles away. As distant as Pluto is, it is still only 1/50,000 of the way to the edge of the solar system. That far away, the Oort cloud of comets drifts past at a stately 220 miles per hour. Three or four times per year, one of these long period comets passes through the solar system. Occasionally they hit something solid, like the moon or the Earth.

Because of the enormous scale, new discoveries are being made even within the Solar System. Neptune was originally thought to have two moons, until the unmanned spacecraft Voyager discovered six more. In the past 20 years, the number of known moons in the Solar System has grown from 30 to more than 90.

Space is so enormous it is highly unlikely that man will ever travel outside the Solar System, according to Bryson. He argues that just traveling to the moon was an enormous feat for humans. Proxima Centauri, in Alpha Centauri, is 100 million times farther than the moon. It would take the fastest space ship 25,000 years to cover the distance. In order to do so, astronauts would have to travel through a vacuum more perfect than any created by man on earth. The average distance between stars is over 20 million million miles.

The section proclaiming the impossibility of space travel is one of Bryson's least convincing. While the distances are certainly daunting, 300 years ago no one would have suspected that man would someday walk on the moon, or spend weeks orbiting in a space station. Many scientists of the time deemed flight impossible, proclaiming that man was never meant to fly like a bird. Few envisioned regular space shuttle service to an orbiting international space station. Bryson's conclusions also fail to take into account further leaps in technology and knowledge. The unique structure of space, discussed in the previous chapter, means every part of space is connected to every other part, much the way the surface of a marble is connected. This opens the door to a technology that would circumvent traditional ideas of distances, opening doorways to distant galaxies. It would be more accurate to say that with current technology, interstellar space travel is impossible.

Bryson uses humor deftly to humanize scientists and make scientific theories easier to grasp. His description of Percival Lowell's big mistake in believing that irrigation canals existed on Mars is hilarious. He also gives credit to such unassuming heroes as the untrained but hardworking Clyde Tombaugh. Bryson's purpose is not to ridicule scientists' eccentricities, but to humanize them. In doing so, the author debunks the popular myth that science and scientists are boring.

Part 1, Chapter 3

Part 1, Chapter 3 Summary and Analysis

The quiet and cheerful Rev. Robert Evans is very good at finding dying stars. From his home in Australia's Blue Mountains, about 50 miles west of Sydney, he searches the skies with a 16-inch telescope. Before Evans started searching in 1980, less than 60 supernovae were located by all scientists since the invention of the telescope. By comparison, between 1980 and 2003, Evans discovered 36 supernovas by himself, using a simple telescope in his backyard.

A supernova is a dying star. Stars die all the time. The fact that scientists can view the North Star, which is 680 light years away, proves that it was still shining in the 1400s. Only about 6,000 stars are visible to the naked eye from Earth. Of these, only about 2,000 can be seen from any one point on the planet. With binoculars one can see 50,000 stars and with a two-inch telescope, 300,000. Using his 16-inch telescope, the Rev. Evans can see 50,000 to 100,000 galaxies, each containing tens of billions of stars. Even so, supernovae are rare and faintly visible for only a few weeks or months. Evans discovered an average of two new supernovae per year from 1980 to 1996. He even discovered a new type of supernova, called an Ia supernova. It's important because it always explodes the same way, so it can be used as a standard candle to measure the expansion rate of the universe.

When a giant star, much bigger than the sun, dies, it collapses and then explodes, releasing the energy of 100 billion suns in an instant. For a time it burns brighter than all the stars in its galaxy. Most supernovae are so far away that from Earth they appear as a faint twinkle, shining for a few months where no star was located before. Such an explosion nearby, within 10 light-years or so, would be fatal to all life on Earth. Humans don't have to worry, though. Only specific types of stars become supernova, and none of those stars are anywhere near the sun. Supernovae powerful enough to be seen with the naked eye from Earth have been recorded six times in history, including events in 1054 and 1604. The most recent was in 1987 in the Large Magellanic Cloud 169,000 light-years away from our planet.

Today, most astronomers use digital cameras and computers to search for supernovae. Telescopes take thousands of pictures that are analyzed by a computer for differences. In just five years, the inventor of this system, Saul Perlmutter, and his team found 42 supernovae.

Supernovae are significant in one other way. When the Big Bang occurred, it created many light gasses but no heavy elements like carbon or iron. Heavy elements are essential for life and can only be created at temperatures hotter than the hottest stars. For a long time, no one could understand how supernovae came to be. Cosmologist Fred Hoyle was finally able to explain their existence. A controversial and irritating man, Hoyle coined the derisive term "Big Bang" while trying to refute the theory. He was the first to propose nucleosynthesis. In 1957, Hoyle showed how heavier elements could be formed inside an exploding supernova. Shamefully, one of Hoyle's collaborators received the Nobel Prize, but Hoyle was never honored.

New solar systems, according to Hoyle's theory, coalesce from gaseous clouds formed by exploding stars. This resulted in the current view of the origins of the universe. Some 4.6 billion years ago, a giant swirl of gas and dust 15 billion miles wide accumulated in this region of space. Gradually the material began to coalesce, with 99.9 percent of the mass going to create the sun. The remaining particles, attracted by electrostatic forces, coalesced into the planets. In "just" 200 million years the Earth was formed, a molten mass subject to constant bombardment from floating debris.

About 4.5 billion years ago, an object the size of Mars struck Earth. This collision blew out enough material to form the moon. Within weeks, the newly separated material had formed a clump, and within a year it became the spherical rock that is the moon. Most of the material came from the Earth's crust instead of the core, which accounts for the fact that the moon has so little iron in its composition. This theory of the moon's formation is usually presented as a modern development. In fact, Reginald Daly of Harvard first proposed it in the 1940s, although no one paid any attention to it for decades. For over 500 million years, the Earth was pelted by space debris including comets and meteors. These brought water to fill the oceans and other elements to ensure the formation of life.

As the Earth grew to 1/3 of its current size, it began to develop an atmosphere of carbon dioxide, nitrogen, methane and sulfur. This atmosphere produced a powerful greenhouse effect, which was good, since the sun was much dimmer at that time. Without the large amount of carbon dioxide, the Earth would probably have frozen over permanently, and life on the planet might never have been possible. This was the hostile environment in which life first grew.

Bryson marvels at the miraculous coincidences that resulted in life's formation in such a hostile environment. He means, of course, an environment hostile to humans in their current form. It never seems to occur to him that as the planet's atmosphere changed, life adapted to accommodate it. If the Earth had changed to an environment that contained more carbon dioxide, or was significantly colder, it is likely that life would have adapted to that, as well. Although Bryson diplomatically avoids taking a direct stand on the existence of a deity, he practices determinism, the conceit that humans are the perfect, inevitable pinnacles of creation, the only higher-life form imaginable.

Part 2, Chapter 4

Part 2, Chapter 4 Summary and Analysis

Scientists in the 17th and 18th centuries were preoccupied with learning as much about the Earth as possible - its size, age, exact location in space and most of all, its origins. The colorful, multi-talented astronomer Edmond Halley entered into a wager with Sir Christopher Wren, an astronomer who designed immortal cathedrals in his spare time, and Robert Hooke. Hooke had a propensity for taking credit for other people's ideas, and is best remembered as the first person to describe a cell. Wren promised 40 shillings, an amount equal to several weeks' pay, to the first man who could determine why planets orbited in an ellipse, instead of a circle.

Halley was certain that the answer had something to do with the inverse square law. Determined to win the prize, Halley approached Sir Isaac Newton. The brilliant, solitary and paranoid Newton explained that he had worked out the calculations, but was unable to find them in the clutter of his workroom. Under Halley's prodding, Newton reworked the calculations. This sparked a two-year reverie from which Newton produced his masterwork, *Mathematical Principles of Natural Philosophy*, better known by its Latin title, *Principia*. At the heart of the work were Newton's three laws of motion and the law of gravity. Newton's laws explained everything from the orbits of planets to the motion of tides and the trajectory of cannonballs.

Halley had suggested that the distance from Earth to the sun could be calculated from the transits of Venus. During these rare events, Venus travels in front of the sun. Once the distance from the Earth to the sun was calculated, it could be used to figure the distances to all the other planets. Unfortunately, there were no transits of Venus during Halley's lifetime. Instead, a French astronomer named Joseph Lalande used triangulation data collected by Captain James Cook to estimate the mean distance of the Earth at 150 million kilometers. This was refined in the 19th century to 149.59 million kilometers.

Henry Cavendish, a brilliant English scientist, first determined the weight of the Earth using an apparatus containing weights, counter-weights and pendulums that he inherited from John Michell. Viewing the delicate contraption via telescope through a keyhole in an adjoining room, Cavendish determined in 1797 that the Earth weighs about 5.9725 billion trillion metric tons. The size, shape, weight and orbit of the Earth were all known by the late 1700s. All that remained was to determine its age. Amazingly, as Bryson writes, "human beings would split the atom and invent television, nylon and instant coffee before they could figure out the age of their own planet." Determining the age of the planet would introduce a new science, geology.

Throughout the book, Bryson's tone is informal. He includes many amusing anecdotes about scientists and their eccentricities. He conveys information powerfully with memorable examples. In particular, Bryson uses everyday objects to convey the relationships between unimaginable distances and forces. The point of view throughout the book is sweeping and cosmic. Bryson offers a scientifically accurate view of nature and humanity that is seldom encountered in popular non-fiction. He uses great skill in keeping the topic fresh and interesting.

Part 2, Chapter 5

Part 2, Chapter 5 Summary and Analysis

James Hutton was a wealthy Englishman with many interests, including geology. Like many people, he pondered why fossils of seashells were so often found on mountaintops. Many theories were proposed in the late 1700s including explanations for natural occurrences such as floods, volcanoes and earthquakes. However, none of the theories was very convincing. Erosion suggested that all hills should be worn smooth, yet there were many mountains. Hutton suggested that the fossils were not caused by a cataclysmic event. Instead, he suggested that all the natural forces that had formed the Earth were still working, slowly and imperceptibly. He proposed that fossils were raised along with the Earth when heat from inside the Earth formed the hills. Hutton's paper was written in indecipherable prose. Half of it was comprised of quotes from French scientific works, written in French. After his death in 1807, a scientist named John Playfair rewrote much of his work. It was still 200 years before the theory of Plate Tectonics was widely accepted. Hutton's theories were so influential that in the 1980s, geologists were reluctant to accept the idea that a catastrophic event accounted for mass distinctions, such as dinosaurs.

Still, scientists were in a quandary about the actual age of the planet. James Usser, an Archbishop of the Church of Ireland, pronounced that based on the book of Genesis, the Earth had definitely been created at noon on October 23, 4004 B.C. No serious geologists ever accepted this theory. The Reverend William Buckland, a serious geologist himself, argued that the biblical phrase "in the beginning" could encompass millions and millions of years. Most thinking people agreed that the Earth was ancient.

When one scientist suggested that the Earth could be as old as 98 million years, he was accused of heresy. Other scientists argued that regardless of the type of fuel the sun used, it could not burn continuously for more than 10 million years without consuming all its fuel. This seemed to contradict the fossil evidence, which suggested that some species were millions of years old. It would be many years before this dilemma was resolved.

The major geological eras are the Precambrian, Paleozoic, Mesozoic and Cenozoic eras. Different scientists recognize 12 to 20 periods or systems within those eras, including the Cretaceous, Jurassic and Silurian periods. Charles Lyell introduced a series of epochs to cover the periods since the dinosaurs called Pleistocene, Pliocene, Miocene and Oligocene in the 1800s.

Part 2, Chapter 6

Part 2, Chapter 6 Summary and Analysis

In 1789, a massive thighbone was found in New Jersey. The discovery was so little heralded that no one remembers the name of the finder and the bone itself has been permanently misplaced. The owner sent it to Dr. Caspar Wistar, who placed this first dinosaur bone in a storeroom for 50 years until it disappeared. Wistar missed the opportunity to become, as an American, the first person to describe a dinosaur.

In France, the Compte de Buffon was claiming that everything in the new world was inferior to the old. Water was stagnate, soil unproductive and life forms necessarily small, weak and frail. De Buffon accused the indigenous people of the new world of being tiny and bird-like, with undersized sex organs and a low sex drive.

Meanwhile, Georges Cuvier of France was compiling the first written description of an enormous creature from the new world, the Mastodon. Cuvier noted that the creature had been as fierce as a tiger, and was now extinct. An obscure English surveyor named William Smith noted that fossils occurred in strata, with the same species frequently occurring together. This raised the question of how some species had managed to survive. Even more troubling was the reason why others had perished. These extinctions appeared to have occurred repeatedly, ruling out the explanation of a single biblical flood.

A variety of scientists began to describe the enormous creatures, including Gideon Algernon Mantell and the Rev. Buckland in England. Richard Owen, an anatomist, coined the term paleontology for the young science. He also named them dinosaurian, meaning "terrible lizard." It was a misnomer, since as Owen knew very well, many were herbaceous and all were reptiles, not lizards. As bones continued to be found, scientists became troubled. In some areas of the new world they were literally falling over huge fields of bones. As the 20th century dawned, it became clear that there were simply too many bones to have accumulated in 20 million years, the supposed age of the Earth.

Bryson deftly sidesteps any argument about creationism. While he never alludes to God or Mother Nature, or suggests any consciousness behind life, he also never refutes any of those theories. This is most apparent in his comparison of the views of Rev. Buckland and Archbishop Usser. While Bryson clearly accepts current scientific theory, he does nothing to discredit a modified version of divine creation. Although much of Bryson's discussion of the creation of the universe touches on religious belief, he only addresses religion directly in this chapter.

Part 2, Chapter 7

Part 2, Chapter 7 Summary and Analysis

In 1896, Henri Becquerel of Paris accidentally left a packet of uranium salts on a wrapped photographic plate in a drawer. Mysteriously, the plate was ruined by an emission from the salts. Becquerel turned the matter over to a graduate student, Marie Curie, to investigate along with her husband Pierre. In 1903, the Curies and Becquerel were awarded the Nobel Prize in physics for the discovery of radioactivity.

Radiation was believed to be so energetic that it must have healthful properties. It was routinely included in some toothpastes and laxatives. Into the 1920s, some hotels advertised the therapeutic effects of their radioactive mineral springs. Scientists now know, of course, that radiation in high doses is toxic. Even low doses can induce cancer, such as the leukemia that killed Marie Curie in 1934.

At McGill University in Montreal, a New Zealand-born farm boy named Ernest Rutherford suggested that radioactive decay was responsible for much of the Earth's warmth. He noted that uranium decayed into lead at a constant, reliable rate. This meant it was possible to date the age of a sample of uranium from the amount of decay. While dating some samples, Rutherford discovered that the uranium, and presumably the Earth, was 700 million years old. His discoveries were met with a great deal of resistance.

Part 3, Chapter 8

Part 3, Chapter 8 Summary and Analysis

One of the most amusing stories involving a scientific career involves Max Planck, who in 1875 was wavering between a career in math or in physics. He was advised not to choose physics, because all the important discoveries had already been made. Fortunately, Planck ignored the advice and ultimately did much work on entropy, for the age of quantum theory, the idea that energy is not continuous but divided into tiny packets called quanta, still lay ahead.

A series of papers by an unknown Swiss patent clerk began the new age in 1905. The young man had no university affiliation and no lab access. His papers seemed to contain pure, original thought, with no footnotes or citations, almost no math and no references to previous work. This amazing scientist, Albert Einstein, suggested that mass and energy were actually the same thing. Even a small amount of mass, a single molecule, could release an amazing amount of energy - so amazing that even the Hiroshima bomb released less than one percent of the potential energy of its mass.

Einstein also suggested that space and time are not absolute. They are relative to the observer. Just as a radio may sound loud if you're in the same room but faint if you're a block away, space and time vary depending upon the observer's location in relation to them. Space is variable, changing and has shape. Space and time are actually two manifestations of the same thing, called spacetime. Gravity, according to Einstein, is merely the result of a massive object bending the spacetime surrounding it. "Physicists as a rule are not overattentive to the pronouncements of Swiss patent office clerks, and so, despite the abundance of useful tidings, Einstein's papers attracted little notice," Writes Bryson.

Einstein's theories explained many things. Suddenly it was apparent how radiation worked. Stars could burn for billions of years by efficiently converting their huge mass to energy. Rutherford's suggestions about the age of the Earth began to make sense. Einstein's papers explained that the speed of light was constant. One of the few flaws in Einstein's theories was that they suggested that the universe must be either expanding or contracting. Since the prevailing knowledge of the time was that the universe was static, Einstein invented a "universal constant," essentially doctoring his equations to conform to the idea that the universe was fixed and eternal.

This dilemma was resolved by a young man with the intergalactic name of Vesto Sliper, who was actually from Indiana. Working in the Lowell Observatory in Arizona, Sliper discovered through spectrographic readings that distant stars were moving away from us. The farthest stars were moving the fastest, suggesting that the entire universe was expanding. Partly because of Lowell's disrepute, Sliper's work was ignored.

Instead, the glory for "discovering" that the universe is expanding went to Edwin Hubble. Hubble was brilliant, handsome and led something of a charmed life. He became the most outstanding astronomer of the 20th century. In 1919, Hubble took over the Mount Wilson Observatory in California and made a series of outstanding discoveries. At the time, the only galaxy known was the Milky Way. Today, scientists know that there are over 140 billion galaxies. If galaxies were frozen peas, they would fill London's Royal Albert Hall.

Hubble's discoveries were made possible partly by the work of Henrietta Swan Leavitt, a remarkable woman who held a lower level job at the observatory. Hubble combined the work of Leavitt and Slipher, measuring defined points in space and discovered that a distant puff called M31 was not a formless gas cloud, but a galaxy 100,000 light-years wide and at least 900,000 light-years away. The universe was far vaster than anyone had imagined.

All the galaxies were moving, with the more distant ones moving faster. This was frightening news for many people, because it suggested that the universe had a beginning and an end. According to Newton's laws, a universe that wasn't static would eventually collapse in on itself. All that was left to complete current knowledge was for an MIT trained Belgian priest-scholar named Georges Lemaotre to put the ideas together into what would eventually be called the Big Bang Theory. Lemaotre's work was so far ahead of its time that it was largely ignored.

Part 3, Chapter 9

Part 3, Chapter 9 Summary and Analysis

Caltech physicist Richard Feynman has pointed out that the most important scientific discovery is that everything is made of atoms. Solid objects, water and even seemingly empty air are composed of tiny particles called atoms. Chemists usually think in terms of molecules, which are composed of two or more atoms. Molecules are so tiny that an object the size of a sugar cube may contain 45 billion billion molecules. Half a million atoms set side-by-side could fit in the width of a single human hair.

Besides being very abundant, atoms are also exceedingly durable. When an organism dies, its atoms disassemble and form new combinations such as a leaf, a drop of water or another person. Some experts estimate that each human contains up to a billion atoms from William Shakespeare to Genghis Khan, Beethoven and Buddha. By current estimates, atoms can survive 1035 years (10 followed by 35 zeros.) Bryson wryly notes that because this is only true of people who have been dead long enough for their atoms to disburse, no one alive today contains any atoms from Elvis Presley.

John Dalton, a poor English Quaker, pointed out the existence of atoms in the early 1800s. Dalton was brilliant but largely self-educated. By the age of 12, he was put in charge of the Quaker school in his small hometown. This is less remarkable when one considers that at 12, Dalton was reading Newton's *Principia* in its original Latin language, among other tomes. During a long life, the retiring, unassuming Dalton wrote many volumes on subjects as diverse as meteorology and grammar. His most important theory suggested that everything was made up of tiny, immutable particles called atoms. One hundred years later, Einstein's paper on Brownian motion confirmed the existence of atoms.

Scientists argued over the structure of the atom. Some argued that they must be cubic, in order to stack easily. Others saw atoms as shaped like a cinnamon bun studded with electrons like raisins. Ernest Rutherford was a rather uninspired physicist at Cambridge University who was terrible at math. Teaching classes, he would sometimes be unable to work out the equations he had written on the board, telling the students to figure it out on their own. He is famous for saying, "All science is either physics or stamp collecting." Ironically, Rutherford was awarded the Nobel Prize in 1908(for chemistry, not physics.

One of Rutherford's assistants was Hans Geiger, who famously invented the Geiger counter, a radioactivity detector. Geiger was a famous Nazi who betrayed many of his Jewish colleagues. Despite his flaws, Rutherford was tenacious and open-minded. He worked out that the structure of atoms must be mostly empty space with a small, dense nucleus. Another scientist has expressed it this way: If an atom were the size of a cathedral, the nucleus would be the size of a fly. The fly, or nucleus, would be thousands of times heavier than a cathedral, however.

Atoms are composed of protons, neutrons and electrons. Protons have a positive charge and form the dense atomic nucleus with neutrons, which have no charge. Electrons have a negative charge. Most people picture the electrons orbiting the nucleus of an atom like tiny planets, but they are very much mistaken. Like the blades of a fan, neutrons occupy the entire space inside the atom, at once. The difference is that while a fan's blades only appear to occupy the whole space, electrons really do.

Niels Bohr was another of Rutherford's assistants. Bohr famously postponed his honeymoon to write a paper explaining the movements of an electron. Electrons can only exist in certain well-defined orbits around the nucleus of an atom. According to Bohr, when an electron moves from one orbit to another, it makes a "quantum leap." The electron never occupies the intervening space between orbits. It simply disappears from one orbit and reappears simultaneously in the other. This strikes many people as strange, because it's not the way matter behaves in the universe of larger objects.

In 1935, James Chadwick finally identified a neutron. Had the neutron been discovered in the 1920s, an atomic bomb would almost certainly have been developed by Germany well before World War II, according to Bryson.

Scientists were still puzzled over whether neutrons were a wave or a particle. German physicist Werner Heisenberg first tried to explain this with the very complex Matrix Theory. "I do not even know what a matrix is," Heisenberg told a friend at one point. Finally, Heisenberg developed his Uncertainty Principle of quantum mechanics. Put simply, an electron is a particle that can be described in terms of waves.

Heisenberg's Uncertainty Principle states that one can know the path of an electron or its location at a precise instant, but one cannot know both. This is because measuring one will disturb the other. As Dennis Overbye has phrased it, the electron doesn't exist until it is observed. It is everywhere and nowhere, all at the same time. Writes Bryson, "If this seems confusing, you may take some comfort in knowing that it was confusing to physicists, too. Overbye notes: 'Bohr once commented that a person who wasn't outraged on first hearing about quantum theory didn't understand what had been said.' Heisenberg, when asked how one could envision an atom, replied: 'Don't try.'"

In an entertaining chapter, Bryson illuminates the difficulties the average person has comprehending quantum physics. In everyday life, humans are accustomed to matter behaving in a certain way. The problem is that the sub-atomic universe operates under a different set of rules. For example, sub-atomic particles can travel faster than the speed of light, while larger molecules cannot. This duality has troubled many scientists. Einstein devoted the last half of his life in a failed attempt to devise a grand unified theory, which would reconcile the two.

In the sub-atomic world, particles in certain widely separated pairs know what the other is doing, and compensate. It's as if a person had two tennis balls, one in Hawaii and one in China. When the person threw the Chinese ball east, the Hawaiian ball automatically started spinning in the opposite direction. This theory, called Pauli's Exclusion Principle, improbable as it may sound, was proven at the University of Geneva in 1997 when they found that changing the spin of one electron affected its partner seven miles away.

Part 3, Chapter 10

Part 3, Chapter 10 Summary and Analysis

Thomas Midley, Jr. was an engineer turned inventor who, while working at General Motors Research Corporation in 1921, discovered that tetraethyl lead reduces engine knocks. Lead was already widely known to be dangerous, but it was an ingridient in many everyday products from the packaging for toothpaste to pesticides and cans. In fact, lead is a powerful neurotoxin that can cause permanent damage to the brain and nervous system and even lead to death.

By 1923, General Motors, DuPont and Standard Oil had formed the Ethyl Company and began to manufacture tetraethyl lead as a gasoline additive. Workers were soon becoming disabled or even dying from overexposure. Ethyl denied that lead was the cause and even suggested that one large group of workers who suffered irreversible delusions were simply working too hard. Midgley demonstrated the "safety" of the product by pouring it all over his hands. In fact, Midgley knew the dangers well, since he had suffered lead poisoning just a few months earlier and never handled ethyl except in front of reporters.

Midgley turned his attention to refrigerators, which were powered by dangerous, flammable gases. He wanted to create a safer coolant. In the early 1930s, he invented chlorofluorocarbons, or CFCs. They were used in refrigerators, air conditions and spray cans for many years, until the public realized that CFCs destroy the ozone layer. They were banned in the U.S. in 1974, but CFCs can still be legally made by U.S. companies in third world countries until 2010.

The darker side of scientific discovery is revealed with this discussion of Thomas Midgley. The lead and CFCs he developed are still adversely affecting the environment today. Modern humans have 625 percent more lead in their blood than previous generations. Although CFCs have been banned in most countries, they will continue to destroy the ozone layer for many decades to come. Bryson's cautionary message is clear: While science can be a boon, if used unwisely it can destroy the Earth.

Clair Patterson was the premier geologist of the 20th century, and a critical figure in the battle to ban lead from gasoline. In the late 1940s, as a graduate student at the University of Chicago, Patterson was given the task of measuring the lead isotope in ancient rocks to determine the age of the Earth. He found nearly every sample was contaminated with lead, making measurement impossible.

Making an amazing assumption that proved to be correct, Patterson decided the meteorites were leftover building material from the Earth and would be the same age. He obtained several samples and dated them in a sterile lab. There, he determined that the earth was 4,550 billion years old, far older than anyone had imagined. In fact, it was far older than the universe, according to cosmologists.

Patterson turned to the problem of the lead contamination. He needed a way to compare the levels of atmospheric lead today with those in the past. He decided to try ice cores. Since the snowfall in permanently frozen areas like Greenland accumulates in annual layers, he could make comparisons. Patterson had developed ice core studies, the foundation of modern climatological work.

Patterson's studies showed that there is dramatically more lead in the atmosphere today than in centuries past. He began an all-out campaign to have lead additives banned from gasoline, which was opposed by the American Petroleum Institute and the API pressured Caltech to fire Patterson. When that was unsuccessful, they used their influence to cut his funding. Patterson never gave up. Through his efforts, lead additives were eventually eliminated from gasoline. Levels of lead in human blood immediately dropped 80 percent, although they are still much higher than in centuries past. Unfortunately, lead never disappears, so the lead released will remain in the atmosphere indefinitely.

Part 3, Chapter 11

Part 3, Chapter 11 Summary and Analysis

In 1911, C.T. R. Wilson got tired of tramping to the top of Scottish hills to study clouds and invented an indoor cloud chamber, where he could cool and moisturize air. When he fired an alpha particle through it to start a cloud, it left a contrail like an airplane. Wilson accidentally invented a particle detector and proved that subatomic particles did, indeed, exist.

According to modern thinking, the basic building blocks of matter are quarks. Quarks are particles that make up the particles that make up atoms. In the Standard Model, there are six quarks, five known bosons (and possibly a sixth), and six leptons. Quarks are divided into six categories called flavors: strange, charm, up, down, top and bottom. In addition, they are divided into the colors of red, green and blue.

Quarks are held together by gluons, forming protons and neutrons, which compose an atom's nucleus. Leptons form electrons and neutrinos. Quarks and leptons together form fermions. "It is all, as you can see, just a little unwieldy, but it is the simplest model that can explain all that happens in the world of particles," writes Bryson. "Most particle physicists feel, as Leon Lederman remarked in a 1985 PBS documentary, that the Standard Model lacks elegance and simplicity."

Another theory, the Superstring Theory, holds that quarks and leptons are not particles but strings(vibrating strands of energy that oscillate in 11 dimensions. These dimensions include height, depth and width, plus time and seven dimensions that are not known to humans. The advantage of this theory is that it reconciles quantum laws and gravitational laws. A final alternative, called M Theory, includes membranes and is far too complex for the average person to distinguish from insanity.

Despite Bryson's usually lucid explanations, these theories are truly mystifying. Bryson admits that the unconfirmed modern theories about subatomic particles begin to sound like the mad rambling of lunatics. Not only do the theories lack elegance and simplicity, they are close to incomprehensible and seem wholly irrational. Fortunately, he moves quickly from the very tiny to the very large.

Hubble determined the age of the universe to be two billion years old. This was a problem, since geologists had proven that many meteorites and rocks on Earth were far older. Various scientists argued over the value of the "Hubble constant" in his equations, placing the Earth at anywhere from 10 to 20 billion years old. In 2003, NASA, using a satellite, determined that the universe was about 13.7 billion years old, which remains the current estimate.

One remaining problem is that there is not enough matter to account for all the mass that exists in the universe. Up to 99 percent of mass is dark matter. It also appears that the furthest galaxies are accelerating, suggesting that there may be dark energy as well. As Bryson explains, "The upshot of all this is that we live in a universe whose age we can't quite compute, surrounded by stars whose distances we don't altogether know, filled with matter we can't identify, operating in conformance with physical laws whose properties we don't truly understand."

Part 3, Chapter 12

Part 3, Chapter 12 Summary and Analysis

In 1908, Frank Bursley Taylor proposed that the continents had once been a single mass that gradually drifted apart. His theory of continental drift was deemed too crackpot for serious consideration. A German weatherman named Alfred Wegener compared plants and fossil records from various continents and noticed anomalies. How could the same snails exist in Scandinavia and New England? They were clearly too small to swim the ocean. Wegener theorized that all the continents came from a single landmass, called Pangaea that split apart and drifted away.

Most geologists were not going to accept any theory by a meteorologist. Instead, when fossils of the same ancient horses were found in France and Florida, they theorized about an ancient land bridge across the Atlantic Ocean. It did not help that Wegener miscalculated Greenland's westward drift at a mile a year, when it is actually closer to half an inch.

Another problem was explaining where all the sediments from the land went. Each year the rivers carried massive quantities of material into the oceans. There was 500 million tons of calcium alone, every year. After millions of years, the silt should have filled the oceans up. But Harry Hess, using a depth sounder during World War II, found that the oceans weren't covered in miles of silt. Instead, they had canyons and trenches. In fact, core samples taken in 1960 showed that the ocean floor in the mid-Atlantic was much younger than near the continents. Finally, Hess determined that the ocean floor was expanding, being thrust up through a trench in the Atlantic and subducted back into the bowels of the Earth when it reached the continents.

Drummand Matthews and Fred Vine confirmed this with magnetic studies of the floor of the Atlantic. The sea floor was spreading, forcing the continents apart. Since the motion involved the entire Earth, not just the continents, it was eventually dubbed Plate Tectonics. This drifting likely caused the extinction of some species and explains earthquakes and ice ages.

The Earth's crust is formed of eight to 12 large plates and about 20 smaller ones. They all move in separate directions, at different speeds. The relationship between current landmasses is much more complex than originally suspected. Kazakhstan was once part of both New England and Norway. Massachusetts was part of Africa. The Shackelton Range in Antarctica was part of the Appalachians. In fact, according to Bryson, rocks really get around.

Eventually, as the current motion continues, California will float off into the Pacific and become a giant island like Madagascar. The Atlantic will become far bigger than the Pacific and Australia will connect to Asia. There is no longer any doubt. Global

Positioning Systems prove that Europe and North America are drifting slowly apart, about two yards in an average lifetime.

No other planets in the Solar System have Plate Tectonics. They are probably an important part of organic life. The well-being of the planet is tied to human well-being. Bryson introduces a major theme here, that of the environment. This theory suggests that by harming the Earth with CFCs and pollutants, humans may actually be altering the basic structures that make organic life possible.

Part 4, Chapter 13

Part 4, Chapter 13 Summary and Analysis

Since the 1800s, it was recognized that there was something odd about the rocks near Manson, Iowa. In 1953, scientists incorrectly determined that ancient volcanic activity was the cause. In fact, the cause was a huge meteor from outer space, 1.5 miles wide, weighing 10 billion tons, which smacked the Earth at 200 times the speed of sound. It left a hole three miles deep and 20 miles wide. Gradually, over 2.5 million years of ice age, the crater filled in with dirt.

Giuseppi Pizaai of Sicily discovered the first meteor on January 1, 1800. About 1,000 more were identified in the next century. By the early 1900s, astronomers were more interested in other stars than in asteroids. As the 21st century dawned, asteroids attracted renewed interest. As of July 2001, about 26,000 had been identified, half of those in just two years from 1999 to 2001. This is still only a fraction of the billion that exist.

It took a very long time for scientists to accept that some craters on the Earth were created by the impacts of meteors. In the early 1900s, G.K. Gilbert of Columbia University experimented by flinging marbles into pans of oatmeal in a hotel room. He concluded that such impacts formed craters on the moon , but not those on Earth.

Then, in the 1950s, Eugene Shoemaker visited the Meteor Crater in Arizona, the most famous impact site and a popular tourist attraction. Shoemaker, along with his wife and a colleague, David Levy, began to devote their spare time to a systematic survey of the inner solar system for asteroids. These rocky objects orbit in loose formation between Mars and Jupiter. The average distance between them is one million miles. There are more than a billion of these asteroids, tiny planets that never coalesced due to the gravity from Jupiter.

Naming an asteroid doesn't make it safe. Even with a name and a known path, other asteroids and planets affect the orbit. At any moment, it's possible for a permutation to send an asteroid hurtling towards Earth. The best guess is that 2,000 asteroids large enough to imperil civilization regularly cross the Earth's orbit. Millions of others about the size of a house could destroy an entire city. One of the closest encounters occurred in 1991 with the comet 1991 BA, which was not spotted until it passed just 106,000 miles from the Earth. To put this in perspective, that is like having a bullet pass through your sleeve but miss your arm.

In 1993, another comet passed just 90,000 miles away before it was detected. According to Timothy Ferris, these near misses probably occur without being noticed two or three times a week. This is partly because the asteroids are so small they aren't visible until they are a few days away from us. The other reason is that the total number of people on the planet devoted to looking for asteroids is only slightly larger than the staff of an average McDonald's restaurant.

It was exactly such an asteroid impact that made the dinosaurs extinct, a fact that was denied by many scientists for decades. The Chiexulub impact site in the Yucatbn peninsula of Mexico proved to be the actual location. The crater there is 120 miles wide and 30 miles deep. Still, many paleontologists questioned why a relatively small object should present a problem for a planet 80,000 miles wide.

The answer came via the Hubble Space Telescope. In 1994, scientists watched the comet Shoemaker-Levy 9 strike Jupiter. Over the course of a week, the planet was pelted with the comet's fragments. A single chunk, called Nucleus G, struck the planet with a force of six million megatons, more than 75 times the energy of all nuclear weapons on Earth. The impact created surface wounds the size of the Earth.

An asteroid would strike the Earth with no warning. It would become naked to the visible eye just one second before impact. The compressed air under the impact site would instantly rise to 10 times the temperature on the surface of the sun. The meteor would vaporize instantly, with a blast that would kill everything within 150 miles.

Even a relatively small impact would affect the entire planet. From afar, the impact would appear as a flash of blinding light, followed minutes later by a silent rolling wave of darkness. A strike at Manson, Iowa would flatten every structure within 1,000 miles. Every living thing from Denver to Detroit would be killed within minutes. The impact would set off a chain of earthquakes, tsunamis and volcanic explosions. Burning rocks would hail down on the entire planet, setting nearly everything ablaze. Over 1.5 billion people would die the first day. Soot and ash would block out the sun for months or years, disrupting crops and growing cycles. The climate would be affected for 10,000 years. Even with all the destruction, an impact the size of Manson, Iowa would likely cause no extinctions. A few members of each species would survive and reproduce.

Most people assume that scientists could destroy any approaching asteroid with a nuclear warhead. In fact, even if scientists were aware of the asteroid a year ahead of time, they could do very little to prevent it from striking the Earth. Current missiles are not powerful enough to escape the atmosphere, nor do they have guidance systems that would work in outer space. With the Saturn 5 rockets used for moon missions retired, there are no rockets powerful enough to send a human crew to destroy the asteroid. Worse yet, scientists couldn't build one because NASA destroyed the plans for the Saturn launchers.

Even if scientists succeeded against all the odds in blowing the asteroid to bits, it would only turn a massive rock into a dirty bomb. The radioactive pieces would rain down on the Earth with the same force of the original asteroid. The comet that struck Jupiter had been in close orbit around that planet since 1929. Yet, it took scientists more than 50 years to notice it.

Part 4, Chapter 14

Part 4, Chapter 14 Summary and Analysis

In 1971, Mike Voorhies discovered one of the most extraordinary fossil beds in North America. It was a mass grave for scores of rhinos, horses, saber-tooth deer, camels and turtles killed around 12 million years ago. In a remote corner of what is now Nebraska, the animals died from breathing abrasive ash spewed by a volcano. The ash covered a depth of 10 feet, 1,000 miles from its source. That same volcano is active today and is overdue for a major eruption.

Scientists understand much less about the inner core of the Earth than about space. That is partly because it is 3,959 miles from the surface of the Earth to the center. There are three layers: the crust, mantle and core.

The Earth's crust and outer mantle form the lithosphere. The lithosphere drifts on a layer of softer rock called the asthenosphere. This drift occurs very slowly, 10,000 times slower than the movement of an hour hand on a clock. Below the asthenosphere is the pure mantle. The pure mantle accounts for 82 percent of the Earth's volume. Inside the mantle are a liquid core and an inner solid core. Temperatures in the core are about the same as on the surface of the sun.

Earthquakes are measured on the Richtar scale. The strongest earthquake ever recorded was a magnitude 9.5 in the Pacific Ocean near Chile in 1960. The tsunami it created destroyed much of Hilo, Hawaii, 6,000 miles away. The Earth averages two relatively mild quakes per day, of a magnitude of 2.0 or greater. Many occur around the Pacific, but few places are immune. Most earthquakes occur where two tectonic plates meet, such as the San Andreas Fault in California. In general, the longer the period between quakes, the stronger the disturbance. Tokyo, which lies at the juncture of three plates, is a city long overdue for a major earthquake.

Interplate earthquakes can occur anywhere. They affect larger areas. The most famous are a series of three that occurred near New Madrid, Missouri in the winter of 1811 to 1812. The New Madrid quakes knocked down chimneys in Cincinnati, wrecked boats in Atlantic harbors along the East Coast, and collapsed the scaffolding around the Capitol Building in Washington, D.C. Earthquakes have occurred nearly everywhere in the U.S. The only exceptions, so far, are western Texas, Florida and the upper Midwest.

For reasons no one understands, the Earth's magnetic field changes in power from time to time. It was three times stronger during the age of the dinosaurs than it is now. It reverses itself approximately every 500,000 years or so. The longest period for a reversal has been 37 million years, the shortest 20,000. Over the past 100 million years, the magnetic field has reversed about 200 times. It may be in the process of reversing right now. The magnetic force of the Earth has diminished about six percent during the past century. This is a concern because magnetism plays a vital role in preserving life. The magnetic field protects humans from damaging cosmic rays from space.

Perhaps the greatest danger from the Earth is the one that scientists understand the least: volcanoes. In March 1980, when Mt. St. Helen's erupted, American volcano experts had only seen eruptions of Hawaiian volcanoes. It turns out that the Hawaiian volcanoes act very differently. Mt. St. Helen's was evacuated to a distance of eight miles from the volcano, which all the experts agreed was safe. The volcano became a tourist attraction, with helicopter tours. In April, scientists noticed a bulge on the north flank of the volcano. No one recognized the danger of a lateral blast.

On May 18, the entire north side collapsed with an explosion equal to the force of 500 atomic bombs like the one dropped on Hiroshima. A hot cloud rose at 650 miles per hour, killing people 18 miles away. The explosion blew 13,000 feet off the top of Mt. St. Helen's. A 60,000-foot column of smoke and ash rose in 10 minutes. In 90 minutes, ash was dumped on the town of Yakima Washington, 80 miles away. The town received no warning to evacuate because the Sunday morning staff at the local radio and television stations didn't know how to operate the emergency broadcast system. Although the 5/8-inch deposit is modest, it immobilized the town for days. Then as now, the U.S. was unprepared for a volcanic eruption.

Part 4, Chapter 15

Part 4, Chapter 15 Summary and Analysis

In the 1960s, Bob Christensen was studying Yellowstone's volcanic history, when he was struck by a perplexing problem. Although everyone agreed that Yellowstone's geysers and hot springs were the result of volcanic activity, no one could find the volcano. Just at that time, NASA forwarded some satellite photos of Yellowstone National Park to Christensen. He immediately realized that virtually the entire park was a volcano.

Most people think of volcanoes as mountains, like Fuji. In most cases, however, the explosion creates an open pit called a caldera. Yellowstone's pit is 2.2 million acres, a crater more than 40 miles across. This is the permanent record of violence far beyond anything known to humans. The supervolcano rises from 12.5 or more miles down in the Earth. All of the National Park rests on a lake of magma 45 miles across and eight miles thick. This has about the same force as a stack of TNT the size of Rhode Island, piled to the tops of the highest clouds. It could explode, or cause a flood of molten rock. Some think that these superplumes are responsible for blowing the continents apart. There are 35 known superplumes on the Earth. All of them, except Yellowstone, are in the oceans.

The first eruption of Yellowstone was 16.5 million years ago. The most recent was 1,000 times stronger than Mt. St. Helens. Last time Yellowstone exploded, the ash fall covered the entire U.S. west of the Mississippi, plus parts of Mexico and Canada. The last supervolcano to erupt was 74,000 years ago in northern Sumatra. For six years, the Earth experienced a "volcanic winter" as floating ash prevented sunlight from reaching the ground. The total population of humans on the planet was reduced to a few thousand for 20,000 years.

For years, no one was overly concerned about the Yellowstone volcano, because they believed that it was inactive. Then, in 1973, part of the park developed a bulge. It subsided in 1985, and appears to be swelling again. Scientists realized that Yellowstone is an active supervolcano that erupts about every 600,000 years, although volatility makes it hard to predict. The last explosion was 630,000 years ago. It is the largest volcanic zone in the world.

Another interesting scientific event took place at Yellowstone. In 1965, Thomas and Louise Brock took a sample of yellow-brown scum from a boiling pool and examined it for living organisms. They found it was teeming with microbes. Called extremophiles, these organisms live in extreme conditions, such as water that is boiling hot, acidic or containing sulfur. One strain, called *Thermophilus aquaticus* was used by Kary B. Mullis to duplicate DNA from small amounts. This procedure made DNA testing possible, and won Mullis the Nobel Prize in 1993.

Part 5, Chapter 16

Part 5, Chapter 16 Summary and Analysis

As far as anyone knows for certain, life only exists on one tiny wedge of one planet, Earth. The space that's suitable for life is less than 12 miles deep on the Earth's surface. By volume, water covers 99.5 percent of the planet's habitable space.

A surprising amount of the land on the Earth is too hot or too cold to be habitable by humans. Only about 12 percent of the land, or four percent of the total surface of the planet, is suitable. Despite Earth's rigors, other planets are even less hospitable. Even Earth itself was less hospitable in times past.

There are 92 elements occurring naturally on Earth, and about 20 more that have been created in labs. Only 30 are widespread and only six are central to life. Carbon is the 15th most common element, but the one on which most life on Earth is based. Carbon's chemical promiscuity allows it to form long chains of proteins and DNA, perfect for life.

Of every 200 atoms in the human body, 126 are hydrogen, 51 oxygen and 19 carbon. Other elements each play vital roles in maintaining health, including iron, cobalt, potassium, sodium and zinc. Still others like selenium are beneficial in very small doses, but toxic in larger amounts. All of these elements occur in the human body in proportion to their abundance in the Earth's crust.

He also ignores the possibility that if the Earth's atmosphere were mostly ammonia, or its average temperature over 200?F, another life form, even another intelligent life form, might have evolved to suit those conditions.

Finally, Bryson ignores the amazingly lengthy time spans involved. It's quite possible that other intelligent life forms did evolve during the past 4.5 billion years. Venus's inhospitable climate, for example, might well be the result of greenhouse gasses created by an intelligent life form billions of years ago. Although Bryson mentions the fallibility of drawing conclusions after the fact (called post-hoc conclusions), he spends the majority of the chapter doing just that. This fallacy is repeated a few times again in subsequent chapters.

Part 5, Chapter 17

Part 5, Chapter 17 Summary and Analysis

The atmosphere keeps the Earth warm. Without it, the Earth would be a ball of ice with an average temperature of -60?F. In addition, the atmosphere absorbs or deflects a variety hazards, including cosmic rays, charged particles, ultraviolet rays, etc. At 120 miles deep, the atmosphere seems thick. However, if the Earth were the size of a desk globe, the atmosphere would be no thicker than a few coats of varnish.

The first layer of atmosphere, next to the ground, is called the troposphere. This layer contains the majority of oxygen in the air and all water. It accounts for 80 percent of the mass of the total atmosphere. In a fast elevator, one could reach the top of the troposphere in 20 minutes. Anyone would be uncomfortable there, though, because the average temperature is -70?F and the oxygen is thin.

The next layer of atmosphere is the stratosphere. When an anvil-shaped storm cloud flattens at the top, it is pressing against the boundary where the stratosphere begins. It averages 40?F as the ozone absorbs many of the sun's most harmful rays. Next, the mesosphere averages -130?F. The topmost layer, the thermosphere, is at 2,700?F or more. At that height, there are few molecules to conduct heat. Even then, a spaceship approaching at an angle of more than six degrees, or too fast, will strike enough molecules to combust.

Oxygen is thin even a few thousand feet above sea level. This results in nausea, frostbite, confusion and exhaustion that are familiar to Everest climbers. The upper limit for humans to survive seems to be 18,000 feet. Mine workers in the Andes work above that elevation, but return below it to sleep each night. People who live in the highest elevations are often adapted to the low oxygen conditions. They have large chests and lungs, and many more red blood cells.

Meteorology as a science didn't really start until the turn of the 19th century. This was partly because no accurate thermometers existed. Daniel Gabriel Fahrenheit, a Dutch instrument maker, designed the first precise bore for a thermometer in 1717. Fahrenheit's scale inexplicably established 32?F as freezing and 212?F as the boiling point. In 1742, Anders Celsius, a Swiss astronomer, designed the Celsius thermometer. Interestingly, he initially established 0?C as the boiling point and 100?C as freezing. The two were soon reversed, providing the thermometer used by scientists today.

English pharmacist Luke Howard, the father of meteorology, gave the cloud types their names in 1803. These included stratus, cumulus, cirrus and nimbus. An average cloud contains 25 to 30 gallons of water, approximately the same amount as a filled bathtub. At any one time, clouds contain only 0.035 percent of the Earth's fresh water. A drop of rain that falls on soil will likely be evaporated within a few days and converted to rain again within a week to ten days.

Meteorologists consider the oceans and atmosphere to be a single system. The Gulf Stream pushes heat northward, so that Britain and Ireland have warmer climates than other countries at the same latitude, such as Canada and Russia. The Gulf Stream's energy is equal to the world's coal output over a 10-year span. Water warms and cools slowly, making coastal temperatures more stable.

Deep, slow currents called thermohaline currents stir nutrients in the water, encouraging the development and growth of sea life. The sun generates more heat now than when the Earth was newly formed. The climate has remained stable, however, due to tiny sea creatures that use carbon for shells, reducing the natural greenhouse gasses. When these tiny creatures die, they fall to the bottom of the ocean where they are compressed into limestone such as is found at the White Cliffs of Dover in England.

Since 1850, over 100 billion extra tons of carbon have been introduced into the atmosphere by humans. According to Peter Cox, "there is a critical threshold where the natural biosphere stops buffering from the effects of artificial emissions and actually starts to amplify them." This creates fears that the Earth's temperature will increase radically, killing many plants, which will release still more carbon.

Bryson introduces another major theme, that despite its size and age, the Earth is fragile. Human actions, such as destroying the ozone layer and producing greenhouse gasses, have the power to kill most life on Earth, including humans. He adds consolingly that the Earth will likely recover in just 60,000 years. The implication is that mankind would be extinct by then.

Part 5, Chapter 18

Part 5, Chapter 18 Summary and Analysis

The human body is made up of 65 percent water, the most common compound on Earth. It is essential for life, yet it too can be lethal, for it has very unique properties. Although it is liquid at room temperature, water expands when frozen. This means that ice floats, preventing the oceans from freezing solid forever.

All but the smallest fraction of water on Earth is poisonous to humans. Although the water in human tissues, tears and sweat is remarkably similar to salt water in composition, drinking seawater is harmful to the human body. It can cause seizures, brain damage and even death. Altogether, there is 320 million cubic miles of water in a closed system. The water world, or hydrosphere, was formed about 3.8 billion years ago. The Pacific Ocean contains 51.6 percent of the planet's water, the Atlantic 23.6 percent, and the Indian Ocean 21.2 percent. The average ocean depth is 2.4 miles.

Only three percent of all existing water is considered fresh water. Most of that is in ice sheets, with 90 percent located in Antarctica and most of the rest in Greenland. If you were to stand at the South Pole, there would be two miles of ice beneath you. At the North Pole there is only 15 feet of ice. Just 0.036 percent of the total water supply is found in lakes, rivers and reservoirs. At any given time, only .001 percent of all water exists as clouds and vapor.

If all the ice in Antarctica melted, it would raise the level of the oceans by 200 feet. Despite the expression "sea level," the oceans are not level at all. They vary considerably from place to place. The Pacific is 1.5 feet higher at its western edge, due to the Earth's rotation.

The first scientific study of the seas, conducted in 1872, was a 3 ? year British mission aboard the HMS Challenger. The expedition coined a new term for the study of the Earth's seas, oceanography. More than 200 scientists took part in the study. When they discovered undersea mountains, they thought they had discovered the lost continent of Atlantis.

In the 1920s, Charles William Beebe and Otis Barton designed and funded the first bathysphere. The nameless craft set several depth records, eventually sinking to 3,028 feet in 1934. The two men glimpsed strange creatures through their blurry portholes. In 1948, Barton set a new solo record in the craft by descending to 4,500 feet. The father and son team of Auguste and Jacques Piccard designed and built a bathyscaphe called the *Trieste* in 1958. They descended to 13,287 feet in their craft. In 1958, with the support of the U.S. Navy, Jacques Piccard and a sailor descended to the bottom of the Mariana Trench, the deepest point in any ocean at 35,820 feet. Just as they touched down, they startled a flat fish apparently living on the very bottom of the ocean. Man has never again gone so deep into an ocean. Instead, humanity turned its attention to space.

In the 1950s, the Navy funded *Alvin*, a mini-sub for the Woods Hole Oceanographic Institute. More than forty years later, it is still the principal undersea exploration tool for the United States. Even now, scientists have better, more accurate maps of Mars than of the ocean floors. Much ocean research is decidedly informal, even accidental. For example, in 1994 34,000 ice hockey gloves were swept off a Korean ship in the Pacific. Scientists learned a great deal about currents by tracking the gloves, from Vancouver to Vietnam.

In 1977, scientists using Alvin made an amazing discovery. They found colonies of large organisms living on and near deep-sea vents off Galbpagos. The creatures included tubeworms 10 feet long, clams a foot wide, shrimp and spaghetti worms. Far below the reach of sunlight, these creatures feed off bacteria that live on the hydrogen sulfides from the vent. It was the first discovery of life that does not depend on photosynthesis.

Despite humanity's ignorance of the ocean and the creatures in it, for many years the major focus of scientific study was dumping radioactive waste into the ocean. From 1946 well into the 1990s, the U.S. regularly dumped 55-gallon drums of radioactive waste near the Farallon Islands, 30 miles off San Francisco. When the ordinary industrial drums failed to sink, Navy personnel often shot them full of holes. The U.S. wasn't alone in this pollution of the seas. Russia, China, Japan, New Zealand and most European nations also dumped radioactive waste into the ocean. No one has any idea what the effects on the habitat may be.

There is much about marine life that scientists don't understand. Antarctica has little plankton to support complex organisms, yet animal life abounds. Over 15 million crab-eating seals live in Antarctica, making them second only to humans in total population. There are also up to 4.5 million penguins. Despite the enormous number of existing sea creatures, many fish including cod, halibut and orange roughy are in danger of becoming extinct through over-fishing.

The fragility of the Earth's ecosystem, and mankind's abuse of it, is a recurring theme. Poisoning the oceans with radioactive waste and wantonly destroying sea life by over-fishing are just two of the problems. Bryson emphasizes that although many species become extinct through natural causes, mankind has greatly accelerated the process.

Part 5, Chapter 19

Part 5, Chapter 19 Summary and Analysis

Humans are no closer to synthesizing life in a lab today than they were in 1953. The best they're able to create is a green broth of organic compounds, under much more favorable conditions than occur in nature. So far, scientists have been unable to create even one protein and many proteins are required to create life- up to one million different types in the human body.

In order to become protein, amino acids must link. For collagen to form, 1,055 amino acids must join in precise order spontaneously. This is stunningly improbable to occur as a random event. DNA, proteins and cell membranes are all essential for complex life, yet each is useless without the other. This begs the question: How could they possibly have evolved separately and randomly?

The answer is that proteins probably evolved from simpler proteins. Molecules assemble into elemental compounds, leading to the formation of organic molecules that form life. The problem is, no one has ever seen this happen. The creation of life was a one-time event. Every living thing on Earth springs from common ancestors and uses the same building blocks. Whether it's a goldfish or a human, all living things are composed of carbon, hydrogen, nitrogen and oxygen, plus trace elements. All life is one.

Scientists once assumed that life was a recent development. They now know that the Earth has been solid for 3.9 billion years, and there has been life on Earth for 3.85 billion years. Belgian biochemist Christian de Duve suggests that this proves that life is bound to arise, whenever conditions allow. He theorizes that the right conditions exist perhaps one million times in each galaxy.

Bryson indulges in post-hoc reasoning here. He again assumes that humans are the highest possible life form and the only possible form of intelligent life. He assumes that specific proteins are necessary for the development of life, instead of assuming that life developed from the materials available. He also ignores the amazingly long period of time that has passed since the universe was created - 4,550 billion years.

Other scientists wonder if life may have been seeded from space. Lord Kelvin suggested in 1871 that the germs of life were brought by meteor to Earth. This theory gained new credence in 1969 when a carbonaceous chondrite meteor 4.5 billion years old fell on Australia. The meteor was found to contain 74 amino acids and complex sugars called polyols that have never been found outside of Earth before. Since then, several other carbonaceous chrondite meteors have been located, with organic compounds. Halley's comet is about 25 percent organic. "Francis Crick, co-discoverer of the structure of DNA, and his colleague Leslie Orgel have suggested that Earth was 'deliberately seeded with life by intelligent aliens,' an idea that Gribbin calls 'at the very fringe of scientific respectability' - or, put another way, a notion that would be considered wildly lunatic if not voiced by a Nobel laureate," Bryson writes.

The oldest record of life is the fossilized traces of microbes in rocks from Greenland that have been dated at 3.85 billion years old. Back then, there was no oxygen on the Earth for an organism to breath. The atmosphere contained noxious vapors such as hydrochloric acid and sulfuric acid. The sun was much dimmer than it is now, and lightning provided the only light. From these components, cyanobacteria formed and developed photosynthesis, a process that released oxygen. Initially the oxygen bonded with iron, forming rich iron deposits. Eventually, as more was produced, it was released into the atmosphere.

The cyanobacteria became tacky, trapping tiny particles of sand, creating solid structures in shallow water called stromatolites. Stromatolites may resemble a cauliflower, a mattress or a column in structure. Specialized cyanobacteria evolved, creating the first ecosystem. After two billion years, the cyanobacteria had raised the atmospheric oxygen level to 20 percent. This provided fuel for more complex animals. Nucleated cells developed and evolved into multi-cellular beings.

Eventually, more complex organisms evolved and ate the stromatolites. Today, cyanobacteria are practically extinct in the open air. They live on, however, inside each of us. This is literally true, because human intestines contain cyanobacteria that digest food.

Until 1961, scientists assumed that all stromatolites were extinct. They knew of the early organisms only from fossils billions of years old. Living stromatolites, resembling large, grey cowpats, were then discovered in Shark's Bay, a remote corner of Australia. Each contains about three billion organisms per square yard.

Bryson's convincing description of the evolution of cyanobacteria refutes his previous claim that conditions similar to those on Earth today are required for life. It would seem more likely that complex organisms that breathe hydrochloric acids could have developed just as easily had the atmosphere remained rich in hydrochloric acid.

The cyanobacteria saga also calls into question another of Bryson's basic themes: that of the fragile ecosystem represented by the Earth. Over time, by exuding oxygen, cyanobacteria changed the planet's atmosphere, which in turn changed the climate and nearly resulted in their extinction. This procedure is similar to humans' production of greenhouse gasses that cause global warming. It is tempting to argue that just as life on Earth adapted to an oxygenated atmosphere, it would adapt to a warmer climate. One difference is that while the cyanobacteria caused changes over billions of years, humans are changing the atmosphere in just thousands of years, leaving little time for organisms to adapt. Another factor is that while some organisms may adapt to breathe an atmosphere of carbon dioxide, humans would likely not be among them.

Part 5, Chapter 20

Part 5, Chapter 20 Summary and Analysis

Bacteria are the most enduring inhabitants of Earth. They survived for billions of years without us, but humans cannot survive one day without them. They pluck nitrogen from the air and form it into amino acids, a complex industrial process that generates a great deal of heat.

There are innumerable bacteria in and around each person constantly. About 100,000 live on each square centimeter of human skin. They also live in the hair, nose, stomach, eyelashes, eyes and teeth. Each human digestive system contains up to 400 types. Bacteria can create a new generation in 10 minutes or less. A single cell can produce 280,000 bacteria in just one day. They mutate quickly and share genetic code freely. This means bacteria are essentially a giant superorganism. They can eat practically anything, from wood and paint to sulfuric acid.

Bacteria are found everywhere on earth. They are inside rocks, deep inside the Earth's crust and at the bottom of the sea. They live in the boiling mud of Yellowstone and in the icy wastes of Antarctica. One variety is immune to radioactivity. Another bacterium survived for two years in a sealed cameral lens on the surface of the moon. Bacteria can remain dormant for long periods. One scientist claims to have revived bacteria 250 million years old.

Charles Woese has been exploring the genetic sequences in bacteria. He proposed classifying organisms into 23 main divisions, in three new categories: Bacteria, Archaea and Eukarya. Eukarya, or organisms with nucleated cells, would include both plants and animals. Many objected to these classifications, but Woese pointed out that 80 percent of life is single-celled Bacteria or Archaea.

Part 5, Chapter 21

Part 5, Chapter 21 Summary and Analysis

Most life on earth has left no record at all. Less than one out of 10,000 species has made it to the fossil record. Based on the current estimate of 30 billion species since the formation of the planet, Richard Leakey and Roger Lewin suggest the number of known fossilized species is closer to one in 120,000. Fossils represent only the tiniest sample of life on Earth. Large parts of the world have never been explored for fossils.

Nearly 99.9 percent of all organisms die and decompose. Their molecules are put to use in another system. In order to become a fossil, an organism has to be buried in sediment or decompose without exposure to oxygen. Dissolved minerals must replace the bones, and occasionally the soft tissues. The site must remain undisturbed for millions of years until the fossil is found and recognized. Only one out of one billion bones is fossilized. To put this in perspective, that would mean the complete fossil record of all living Americans would be just 50 bones. That's barely one-fourth of a skeleton, spread over 3.6 million square miles. It is unlikely that any of those bones would ever be found.

Trilobites are marine creatures that vary from the size of a beetle to the size of a dinner plate. They suddenly appear in the fossil record 540 million years ago, in what is known as the Cambrian explosion. Some people have used them to refute evolution in favor of an argument for divine creation. Their sudden appearance was a mystery until the Burgess Shale was found in British Columbia. The shale contained 60,000 to 80,000 fossils of soft-bodied creatures preserved by a mudslide. There was great disparity in the anatomical designs of the 140 separate species, and they fit in no known categories.

According to Jay Gould in his book *Wonderful Life*, the Burgess Shale fossils were more diverse than anything alive today. They included bizarre body parts. For instance, the Opabina had five eyes and a nozzle-like snout with claws at the end. The Peytoia comically resembled a slice of pineapple. The Hallucigenia had rows of stilt-like legs. As Bryson explains, "There was so much unrecognized novelty in the collection that at one point upon opening a new drawer Conway Morris famously was heard to mutter, 'Oh fuck, not another phylum.'" Gould insisted that the Cambrian was a period of unparalleled diversity. He implied that paleontologists had to change their notions of man being the culmination of a long, orderly procession of evolution.

Many scientists took umbrage with Gould's book. They had long recognized that the human was not the pinnacle of an orderly evolution. They also insisted that none of the fossils were as strange as a queen termite or a barnacle. Most of the fossils found on the Burgess Shale fit into recognized living phyla. The Hallucigenia actually had spikes on its back, not stilt-like legs. The Peytonia was merely part of another creature.

Actually, the Cambrian creatures didn't emerge suddenly. Complex creatures existed at least 100 million years before the Cambrian period. Just as mammals grew larger over the millions of years after dinosaurs became extinct, some change in environment caused anthropods to grow from microscopic to visible size during the dawn of the Cambrian period.

Part 5, Chapter 22

Part 5, Chapter 22 Summary and Analysis

Extinction seems to be a natural part of the life cycle. During its history, there have been five major extinction episodes on Earth: the Ordovician, Devonian, Permian, Triassic and Cretaceous. In addition, there have been many other smaller ones. During the Permian period, at least 95 percent of all the animals known from the fossil record died out. On average, a species exists for about four million years, which is approximately how long humans have been around.

For most cases, scientists have little idea what killed off species. Prime contributors include changes in global climate, changing sea levels, oxygen depletion of the seas, meteor and comet impacts, huge hurricanes, volcanoes and catastrophic solar flares. There is just too little evidence to determine the exact causes for mass extinctions.

The impact of the KT meteor, which killed the dinosaurs, wiped out 70 percent of life on Earth at that time. Landing in a shallow part of the ocean, it pulverized the sulfur in the seabed, sending gushes of sulfuric acid into the air. For months, it rained acid strong enough to burn the skin. The impact also thrust the Earth into a winter that lasted for years. Given the extreme conditions, it is surprising that 30 percent of the species survived. Certainly, many individuals within those species died. For mammals, the KT impact was a surprising boon. It killed every species of dinosaur and cleared the way for mammals to become the dominant species on the planet.

This chapter is brief and rather inconclusive, because so little is known about the causes of natural extinction. While explaining that extinction seems to be part of the natural life cycle, Bryson emphasizes man's role in the untimely extinction of many species in Chapter 31.

Part 5,Chapter 23

Part 5,Chapter 23 Summary and Analysis

The 1700s introduced an plethora of plant collection, but no definitive way to catalogue them. Carl Linny, the son of a Swiss curate, began to publish catalogs of the known plants. Linny was obsessed with sex, and classified the plants according to their method of reproduction. He even named one genus Clitoria. Despite his odd obsession, Linny's classification system was irresistible. He introduced a binomial system of genius and species that is still in use today. Linny had a talent for identifying the salient points of each species. He was the first to classify whales as mammals.

In the quiet plant world, battles rage over taxonomy, or the naming of plants. Grass collectors will argue to no end whether a certain plant should be named *Aegilops incurvata* or *Aegilops ovata*. Chrysanthemum growers will shamelessly lobby the International Association of Plant Taxonomy to have their favorites restored to the Chrysanthemum genus, from the genus Dendranthema.

Up to 97 percent of all plant and animal life has yet to be discovered. In the 1980s, Terry Erwin saturated a group of 19 rain forest trees seasonally with insecticide. From those 19 trees he collected 1,200 different varieties of beetles. Based on his findings, Erwin estimates that there are over 30 million varieties of beetles worldwide, most of them undiscovered. Other scientists place the estimate as high as 100 million species.

There are several reasons why scientists may overlook some species. One of these reasons is that many species are incredibly small. An average bed pillow likely to contains 40,000 mites. A second reason is that scientists don't look in the right places. In just a few days, scientists discovered more than 1,000 new species of flowering plants in the rain forest in Borneo. That is more than the total discovered to date in North America. There are not enough specialists to search for all possible plant forms. The final reason is that the Earth is simply an enormous place. There are over 30,000 okapi living in the rain forests of Zaire. Yet, this relative of the giraffe was not even suspected to exist until the 20th century. The takahe, a flightless New Zealand bird, was believed to be extinct for over 200 years, until it was discovered living on the rugged South Island. The natural world retains an infinite capacity to surprise.

Part 5, Chapter 24

Part 5, Chapter 24 Summary and Analysis

Even the simplest cell is far beyond the ingenuity, or technology, of man. The human body has 10,000 trillion cells, each with their own purpose. Very little of the internal workings of cells are understood. From nerve cells several feet long to tiny disc-shaped red blood cells, most cells live less than a month, but some, like liver cells, may live for years. Brain cells can last a lifetime.

Robert Hooke was the first person to describe a cell. Van Leeuwenhoek identified tiny animals in water using a rudimentary magnifying device. All cells have an outer fatty casing and a nucleus that contains the DNA. Between the two is cytoplasm. Within the cell, literally millions of objects such as lysosomes, endosomes, ribosomes, ligands and peroxisomes are furiously at work, knocking into each other millions of times per day.

Mitochondria are thought to have originated as captured bacteria. They now live within every cell, preserving their own unique genetic material. The mitochondria convert food and oxygen to ATP, a form of energy that can be used by the body.

Every day millions of cells die in a programmed, majestic self-destruction process. When a single cell proliferates wildly instead of dying, it produces cancer. What is amazing is the smooth way the cells function most of the time, without direction or conscious thought. They direct most bodily functions with ease.

Part 5, Chapter 25

Part 5, Chapter 25 Summary and Analysis

In late 1859, Whitwell Elwin received an advanced reading copy of Charles Darwin's new book. Concerned that there would be a small market for the tome, he encouraged Darwin to write a volume about pigeons instead. Despite Elwin's advice and an unwieldy title*, On the Origin of Sepcies by Means of Natural Selection or the Preservation of Favored Races in the Struggle for Life* sold out its first edition the day it appeared. The book has never been out of print since 1859.

At 22, Darwin was invited to sail on the HMS Beagle as the dinner companion to the captain, Robert Fitzroy. In one of the greatest ironies of all time, Fitzroy had undertaken the voyage because his passion was finding literal proof of the biblical story of creation. He chose Darwin, expecting the divinity student to be sympathetic. For five years, the men shared a cabin, quarreling constantly. Darwin accumulated enough specimens for a lifetime of study. Returning to England in 1836, Darwin spent several years evaluating his samples. In 1842, he created a 230 page "sketch" that outlined life as a perpetual struggle where species survived by natural selection.

Darwin inexplicably took a 15-year break at that point. He married his first cousin, fathered 10 children and spent eight years writing a book about barnacles. By the time he returned to the subject of natural selection, Darwin was in such poor health that he could only work for 20 minutes at a time, but he eventually finished the volume.

The outcry that Darwin's work created was extreme. In 1860, at the British Association for the Advancement of Science at Oxford, Samuel Wilberforce asked T. H. Huxley if he claimed kinship to apes on his grandmother's side or his grandfather's. Huxley replied with an insult, sparking a riot.

Darwin was quite aware of the impact of his theories on religious beliefs of the time, and he even said it made him feel like the "Devil's chaplain." There were two major problems with his theory. First, there was no fossil record to support the theory. The earliest fossils seem to appear in mass in the Cambrian period. Many people believed that this was proof that God had created all the creatures at that time, including man.

The second flaw in Darwin's theory was that the events of the theory simply took too long to reasonable unfold. Evolution (a term Darwin didn't actually use until much later), according to Darwin, occurred over millions of years, far longer than the Earth was thought to have existed. Darwin's theory also left open the mystery of how traits were transmitted from one generation to the next.

In the Austrian empire, Gregor Mendel was working on exactly that scientific mystery. Mendel was a trained scientist and a monk. With two assistants, he spent seven years developing control specimens of seven different varieties of peas that bred true to type.

Mendel grew 30,000 plants over eight years, meticulously tracing the transmittal of traits. Although he never used the word *gene*, Mendel referred to dominant and recessive factors that interacted in a predictable pattern of inheritance. Mendel's work received little recognition and he continued a life of solitary study, growing outstanding vegetables, and studying bees, mice and sunspots. Mendel ended up as abbot of the monastery.

Bryson avoids taking sides in the creationism debate, although he makes it clear that science is on the side of evolution. The original arguments for creationism that are examined are some of the same ones used today.

Part 5, Chapter 26

Part 5, Chapter 26 Summary and Analysis

If someone is married to a person from their own race and country, there is an overwhelming probability that the two of them are distant relatives. In fact, if one looks around a movie theater or park, there is an excellent chance that they are related to most of the people that they see. In a literal sense, all humans are one family.

Human genetic heritage is amazingly similar. Over 99.9 percent of a person's genes are shared with all other humans. The remaining one gene in 1,000 makes each human a unique individual. Each cell contains a nucleus. Inside the human nucleus are 46 chromosomes, 23 from each parent. The chromosomes are made up of DNA strands that contain genes. There is six feet of DNA in each cell of the body, approximately 20 million kilometers in total. The DNA contains 3.2 billion letters of coding.

In 1869, Swiss scientist Johann Friedrich Miescher discovered DNA while examining pus under a microscope. The chemically inert substance was dismissed as unimportant and too simple to convey heredity. DNA consists of just four components: Adenine, cytosine, guanine and thiamine. Adenine always pairs with guanine and cytosine always pairs with thiamine. Like the dits and dots of Morse code, the few genes convey information by their unique combinations. To replicate, DNA divides like a zipper and pairs with its complementary component. About once in a million replications, there is a mistake called a Single Nucleotide Polymorphism, or Snip. Snips can occur anywhere on the DNA and result in the variation that makes each human unique. Most snips are harmless and have no consequences, while others may predispose to a disease. Still others provide an adaptive advantage, such as increased red blood cells at higher altitudes.

Like all organisms, humans are slaves to their genes. In one sense, humans exist as vehicles to replicate DNA - it does not exist to serve humans. Not all DNA instructions are beneficial. The production of reverse transcriptase, for example, allows retroviruses such as HIV to slip into the human body. As far as anyone can determine, reverse transcriptase has no positive effects.

Genes are blamed for many conditions, including obesity, schizophrenia, criminality, alcoholism, shoplifting and homelessness. In fact, it is not so simple. Only a few disorders, such as hemophilia and cystic fibrosis, emerge from a single gene. The majority of traits, from eye color to complex behavior, are determined by groups of genes acting together. This can be an advantage. When important genes are destroyed, others take their place, resulting in normal or even superior individuals.

A remarkable amount of genetic material is shared between species. Humans share over 60 percent of their genes with fruit flies and over 90 percent with mice. When scientists inserted a gene for a mouse's eye into a fruit fly, they expected that the result would be grotesque in an interesting way. Instead, the fly developed an extra, but viable, fruit fly eye. It was able to use the mouse gene, even though the two animals last shared a common ancestor 500 million years ago. Apparently, all life uses the same template, which originated many millions of years ago.

Part 6, Chapter 27

Part 6, Chapter 27 Summary and Analysis

Biological determinism is the belief that human beings are the ultimate and intentional end product of evolution. Although Bryson dismisses it as a fallacy in previous chapters, he indulges in biological determinism in the title of this section, "The Road to Us." The implication is that humankind is the highest possible achievement of nature, instead of just one of 35 million species on earth.

The Earth's thermostat is a delicate instrument. In 1815, a volcanic eruption in Indonesia and the tsunamis that resulted killed 100,000 people. It was the largest volcanic event in 10,000 years and was 150 times as powerful as the eruption of Mt. St. Helen's. The volcano spewed 36 cubic miles of ash and dust, which diffused into the atmosphere and blocked out the sun.

perature of just 1.5?F.

The concept of ice ages was slow to gain popularity among scientists, despite anomalies like the skeletons of arctic reindeer in the balmy south of France. Swiss peasants insisted that giant boulders had been deposited by glaciers. Jean de Charpentier, a Swiss scientist, was the first to suggest that glaciers shaped much of the Earth's surface. The Swiss naturalist Louis Agassiz quickly appropriated his idea. Alexander von Humboldt may have had Agassiz in mind when he noted that the three stages of scientific discovery are "first, people deny that it is true; then they deny that it is important; finally they credit the wrong person." Karl Schimper coined the term ice age when he proposed the radical notion that much of Europe, Asia and North American had once been covered with glaciers.

For a decade, European scientists continued to be skeptical of the ice age theory. It was finally accepted in the U.S. This acceptance was sparked in part by the first scientific expedition to Greenland, which found most of the sub-continent covered in a permanent sheet of ice. Still, the cause of ice ages was a mystery.

James Croll suggested that cyclical changes in the Earth's orbit contributed to changes in climate. Milutin Milankovitch, a Serbian mechanical engineer, elaborated on Croll's theory. Milankovitch suggested that three separate variables in the Earth's orbit interact to produce ice ages. Over 20 years, Milankovitch laboriously computed a table of these cycles in his spare time. Modern techniques of dating have confirmed the relationship between Milankovitch's variations and ice ages.

Most people assume that ice ages are caused by a gradual increase in harsh winters, when in fact, unusually cool summers that fail to melt all the snow are the true cause.

The snow reflects sunlight, exacerbating the cooling effect and producing still more snow. A single unseasonable summer can plunge the planet into an ice age.

Our current temperate climate is recent and unlikely. In ancient times, some 50 million years ago, the world was much hotter than it is now. There were no regular ice ages or permanent ice caps. Antarctica featured a climate that was borderline tropical teeming with plant and animal life.

About 1.2 billion years ago during the Cryogenian period, the Earth was like a giant frozen snowball. The surface of the ocean was covered in ice as thick as half a mile. Even in the tropics, the ocean was covered by ice more than 10 yards thick. Yet, open water must have existed somewhere - perhaps over the deep ocean vents - because, according to scientists, cyanobacteria survived the Crogenian period and these single-celled organisms can only thrive with access to direct sunlight. Volcanoes probably unlocked the frozen Earth by spewing hot lava and gasses into the atmosphere.

The Earth is currently in a period of relative warmth within an ice age, although most people do not think of it that way. The current ice epoch began about 40 million years ago. The modern period of unusual climactic tranquility is called the Holocene. This period of comparative warmth is atypical weather. Such warm spells within ice ages last as few as 8,000 years. The current one has endured for 10,000 years. Currently, permanent sheets of ice cover about 10 percent of the planet, down from 30 percent during the height of the most recent ice age. If North America, Greenland and Eurasia were just 300 miles further north the Earth would be a perpetually frozen ball of ice.

Ice cores from Greenland detail the climate for 100,000 years, showing a surprising instability. About 12,000 years ago, the planet gradually began to warm but was inexplicably plunged back into extreme cold for 1,000 years. In just 20 years, the average temperature dropped by 7?F. This means the climate changed from that of sunny Greece to frosty Scandinavia in just two decades. In Greenland, the change was even more abrupt, with a decrease of 15?F in 10 years. Apparently, the sudden rise in temperatures triggered the melting of ice caps, which diluted the ocean's salinity. The reduced salinity changed the course of the Gulf Stream, which had funneled warm air to the higher latitudes. Such a change would be catastrophic on a highly populated planet.

ocean near Antarctica has increased 2.5?C. One potential threat of this increase is that the unstable West Antarctic ice sheet will collapse. This would increase the sea level by 15 to 20 feet, flooding every coastal city on the planet.

Bryson's warning about global warming is relatively mild. He shies away from identifying pollution by the most developed nations as the cause. He also fails to mention several other hazards of global warming. If the West Antarctic ice sheet melted, the reduced ocean salinity would likely result in more snowfall and bigger icecaps. This would paradoxically plunge the planet into a new ice age. A major volcanic eruption at

Yellowstone would block the sun, destroying all crops for several years and likely ushering in another major ice age.

Part 6, Chapter 28

Part 6, Chapter 28 Summary and Analysis

Our understanding of the origins of humanity continues to evolve. Humans share 98.4 percent of their DNA with chimpanzees. The two were very closely related until seven million years ago, when a new being emerged from the tropical forests of Africa onto the open savannah.

Creatures who walk on two legs, known as bipeds, present unique structural challenges. The pelvis must become load bearing, narrowing in the process. This makes childbirth painful and often fatal. Because of the narrow pelvis, infants are born small and helpless, necessitating male-female bonding. Much of the development of young human children takes place before birth in other complex animals.

Apparently, five million years ago the dominant hominid *Australopithecines*, walked upright. The most famous example of this species is the partial skeleton known as Lucy, discovered in Ethiopia in 1974. Lucy is 3.5 feet tall and while alive could walk and climb. No skull fragments were found, but it is likely that her brain was small. Less than 20 percent of the entire skeleton was found. In fact, scientists do not even know if Lucy was female - her name is based on her diminutive height. Modern humans may not even be descendents of Lucy, since the modern human femur more closely resembles that of an ape rather than that of *Australopithecines*.

Lucy's species was apparently driven from their habitat by an impending ice age, which turned the African jungle to savannah. The *Australopithecines* had hands, allowing them to defend themselves from a distance. They didn't have enlarged brains and didn't use tools. It was more than a million years before a biped came along who did use tools.

It appears that from three million to two million years ago, six hominid species co-existed and then vanished abruptly. In 2001 and 2002, four new species of bipeds were found. The *Kenyan-thropus platyyops* is a contender for the role of human ancestor, as is the seven million-year-old *Sahelanthropus tchadersis*. No one knows why only one species of biped survived. Scientist Matt Ridley suggests that perhaps humans ate the other species.

The *Homo habilis,* discovered in 1964, used rudimentary tools and had a brain that was 50 percent larger than Lucy's. Then as now, the oversized brain contributed two percent of the body's mass, but consumed 20 percent of its energy. For this reason, an intelligent species demands far more food than an unintelligent species of similar size. Large brains may appear to be a liability that evolved accidentally. Bryson suggests there was nothing inevitable about the evolution of humans.

Homo erectus hunted, used fire and complex tools. Scientists disagree on whether or not they had the capacity for speech. They were the first species to care for the weak and frail. Skeletons from Kenya reveal an entirely modern body structure. They are the earliest bipeds known to have cared for the sick*. Homo erectus* is the only hominid to spread across the globe, expanding its range at about 25 miles per year.

Bryson's treatment of this material is not as tightly organized or clear as most other chapters. This may be due to the fact that multiple discoveries about mankind's ancestors were made while he was writing. There are conflicting views among scientists regarding which species modern humans descended from, adding to the confusion.

Part 6, Chapter 29

Part 6, Chapter 29 Summary and Analysis

About 1.5 million years ago, the first hand axe was shaped with a stone. It was an elaborate tool, representing the best technology yet available. Over millions of years, thousands of this tool were created in some locations. One of these is found in Olorgesailic, Nairobi where a primitive stone axe factory seems to have existed for over a million years.

The stone axes were not used merely for utilitarian purposes. They were as long as 18 inches and weighed up to 25 pounds. The largest examples of Acheulean tools, as they are called, seem to have had ceremonial significance. They replaced the older, less effective Oldowan tools. Apparently, when modern man traveled to Asia, he didn't take the tools with him, as he did when he traveled to Europe.

Just how humans became dispersed across the planet is a mystery. Australia was once thought to be inhabited for only a few thousand years. Now, skeletons older than 60,000 years have been found there. The prevailing belief is that humans dispersed across Eurasia in two waves beginning two million years ago with Java Man and Peking Man. Homo sapiens then replaced these groups, perhaps through disease or competition.

How modern man triumphed is not fully understood. Neanderthals were larger and sturdier than their *Homo sapien* counterparts. More importantly, the Neanderthal had bigger brains. They were hardy enough to survive the Siberia-like winters of an ice age, and triumphed for over 100,000 years from Gibraltar to Uzbekistan. In some parts of the Middle East, the Neanderthal and modern man coexisted for tens of thousands of years.

One theory, the multiregional hypothesis propounded by Alan Thorne, holds that modern man evolved from continuous movement between cultures and regions. This theory suggests that humans had parallel evolutions in different regions, including Asia, Europe and Africa. Other scientists feel that the correct explanation is a combination, with parallel evolution in multiple regions and migration with crossbreeding resulting in modern man.

According to a Swedish DNA study, all modern humans descended from just 10,000 people in Africa about 100,000 years ago. Europeans descended from a few hundred Africans just 25,000 years ago. These extremely small numbers of ancestors explain the relatively low amount of genetic variation between humans. As one scientist wryly notes, there is more genetic diversity in a single clan of 55 chimpanzees than in the entire human population.

Bryson's discussion of the tiny number of human ancestors suggests that there may have been an ice age or some catastrophic event that reduced the human population 100,000 years ago. It does seem ironic that humans are able to find so much to disagree about, when they are so closely related. It is somewhat comforting to think that such a small number of individuals could generate the world's current population. This theory also lends some support to a creationist view of humanity's origins, which is absent from the book to this point.

Part 6, Chapter 30

Part 6, Chapter 30 Summary and Analysis

Sometime during the 1680s the last dodo in Mauritius was killed either by a bored sailor his pet monkey. At about that same time, Newton's *Principia* was being published. Bryson points out that these represent the best and worst of human scientific achievement.

Around 1755, the director of the Ashmolean Museum in Oxford pitched the last stuffed dodo into a fire. A horrified employee snatched it out in time to save the head and a leg. As a result, no one really knows what the bird looked or sounded like. No one has a dodo egg and scientists know nothing about its mating habits. After only 70 years of exposure to humans, the plump, flightless, notably unintelligent member of the pigeon family was extinct.

Throughout much of human history, studying wildlife meant capturing it and killing it. Scientists in the 1800s expressed great joy in "bagging" the last of a species. Even before naturalists began shooting birds and mammals for enjoyment, primitive humans hunted many larger species out of existence. The Earth was once home to many creatures the size of the modern rhino. In North and South America, 75 percent of large animal species became extinct and in Australia, that number is 95 percent. In Europe and Asia, where species had more time to adjust to the gradual migration of humans, up to half were hunted until extinct. The largest challenge for American and Australian species was that they lacked a natural fear of man.

In past centuries, an average of one species of animal became extinct every four years. Today, the pace is 120,000 times as fast. Counting plants and animals, in 1979 an estimated two species per week were becoming extinct. Today the number is 600 to 1,000 per week, or perhaps even more.

Bryson makes a compelling case that man's greatest embarrassment is contributing to the extinction of so many animals. While many species have become extinct throughout time due to natural causes, the current rate of extinction is unprecedented. Bryson bemoans the tendency of naturalists and wealthy collectors in the 1800s to proudly kill species off, but he neglects to mention that this position was usually supported by their religious beliefs. Many believed well into the mid-1900s that man was put on earth by God to have dominion over the animals. To many, this made hunting for sport a part of the natural order.

Characters

Arno Penzias

Robert Wilson

Percival Lowell

Marie Curie

Fritz Zwicky

Clair Patterson

Edmond Halley

Annie Jump Cannon

Henrietta Swan Leavitt

The Reverend Robert Evans

Rosalind Franklin

Fred Hoyle

Mary Anning

Henry Cavendish

Neils Bohr

Edwin Hubble

Albert Einstein

Clyde Tombaugh

Objects/Places

The Universe

The universe was created in a single eruption from a singularity much smaller than an atom. In "less time than it takes to make a sandwich," the current expanding Universe and most of the elements in it were created.

The Earth

Life on Earth may be due to the planet's molten core, which spews energy into the atmosphere and distributes heavier elements.

Atoms

All matter is made up of atoms. Atoms are eternal; when a person dies, their atoms are released into the ecosphere through decomposition and used to form other organisms. Each person alive today probably contains atoms from Shakespeare, Beethoven and other historical figures.

Paired Electrons

Swiss scientists proved the validity of quantum physics by isolating paired electrons seven miles apart. When they caused one electron to spin, the other spontaneously spun in the opposite direction.

Stellar's Sea Cow

Stellar's sea cow is a walrus-like animal identified in the 1740s by a shipwrecked Russian naturalist. It was about 30 feet long and weighed around 10 tons. Just 27 years after it was identified, it was extinct. It is just one of thousands of species of large animals (over two tons) that are now extinct because of humans. Many large species in North America and Australia were hunted out of existence because they had no fear of humans.

Tubeworms

In 1977, scientists found colonies of large organisms living on and near deep-sea vents off Galbpagos. The creatures included tubeworms 10 feet long, clams a foot wide, shrimp and spaghetti worms. Far below the reach of sunlight, these creatures feed off bacteria that live on the hydrogen sulfides from the vent. It was the first discovery of life that does not depend on photosynthesis.

Alvinellid Worm

One creature discovered living near ocean vents was the alvinellid worm. It lives in the margins of vents, with its head in water 140?F warmer than the water at its tail. This amazed scientists, who had believed that no complex organism could endure water hotter than 130?F.

Cyanobacteria

In the Earth's distant past, a massive ice epoch killed all life on the surface of the Earth, except cyanobacteria. These single-celled animals release carbon dioxide "greenhouse gasses" into the air, eventually producing more complex forms of life and influencing the Earth's current temperate climate.

Slime Molds

This bacterium exists as single-celled organisms similar to amoeba when conditions are good. When conditions become less favorable, the single cells gather together and form a slug. The slug climbs to a more exposed area, such as the top of a leaf pile. From there, the slug turns into a plant. The plant grows a stalk and releases spores, which disperse and become single-celled organisms again. Genetic analysis shows that slime molds are not closely related to anything else in nature, and some are not even closely related to other slime molds.

The Yellowstone Volcano

Of 13 super volcanoes in the world, only one exists under land, at Yellowstone National Park. An explosion at Yellowstone is long overdue and would likely rain superheated rocks over a 1,000-mile radius, killing most life as far away as St. Louis and Chicago. The resulting ash fall would have a devastating effect on life on Earth and would render the continental U.S. west of the Mississippi River uninhabitable.

The Polar Icecaps

Throughout most of the Earth's history, the planet was far too warm for humans to live on. Antarctica had a tropical climate and was covered with jungle plants and animals. The current ice epoch began more than 50 billion years ago, for unknown reasons. Currently, about 10 percent of the Earth's surface is permanently buried under ice.

The Chiexulub Impact

The Chiexulub site in the Yucatbn peninsula of Mexico is the location of the meteor impact that resulted in the dinosaurs becoming extinct. The crater is 120 miles wide and 30 miles deep.

The Moon

At 25 percent the size of the planet, the Earth has proportionally one of the largest moons in the Solar System. The Moon was formed billions of years ago, when the still-coalescing Earth had a collision with an object the size of Mars. The impact blew out a large chunk of the Earth's crust, which eventually coalesced into the Moon.

Themes

The Universe is Vast, Complex and Inhospitable

A major theme of Bryson's work is the vastness of the universe. In fact, space is so vast and complex that some of the information about it seems quite fantastical. It is possible that the Big Bang has actually occurred millions of times, creating a universe with new properties each time, like an artist painting over the same canvas.

Some notable scientists believe that there are an infinite number of galaxies in different dimensions, with different attributes. It seems highly probable that there are at least seven to 10 dimensions, of which humans can perceive only four (length, width, depth and time.) Within the familiar four-dimensional universe, there are over 140 billion galaxies. They contain an estimated 10 billion trillion planets, only 70 of which have been identified.

Even the tiniest part of the universe is vast, when one considers that every single object the size of a sugar cube contains 45 billion billion atoms, composed of still smaller electrons, protons and neutrons. This tiny world is also quite fantastical, considering that electrons apparently do not exist until they are measured and can disappear from one orbit and reappear instantaneously in another orbit in a "quantum leap." Atoms are composed of truly amazing particles called Quarks. Quarks come in three colors: red, green and blue. They are also divided into six flavors: up, down, top, bottom, strange and charm.

The Earth is Fragile and Dangerous

Bryson points out that at this stage scientists know far more about the topography of Mars than about the center of the Earth or the bottom of the Earth's seas. What humans do know about the Earth is often frightening. Throughout much of Earth's history, it has been too hot for humans to exist. Then, about 150 billion years ago, for an unknown reason, the Earth's climate cooled. It entered a series of ice ages, interspersed with warmer eras. Ice caps on the Polar Regions are a recent development in the planet's history, geologically speaking.

It appears that the ice ages are caused by cooler summers, not by cold winters. In a cool summer, not all of the previous winter's ice melts in the northern latitudes. The increased snowfields reflect more of the sun's rays back into space, lowering temperatures even further. Each year the ice advances as much as 25 feet. Interestingly, the Earth is currently in a relatively temperate period within an ice age. Up to one million years ago, ice caps covered as much as 30 percent of Europe and North America. Today, 10 percent of those regions is covered in permanent sheets of ice.

At one point in the Earth's history, the entire planet was a solid, frozen snowball. Sheets of ice covered the entire surface of the Earth, except for a small section at the Tropics.

Even in southerly latitudes, the ocean's ice was many yards thick. This "snowball Earth" may have ended due to the molten core of the planet. Volcanoes spewed hot gasses and ash into the air, melting some of the ice.

A major volcanic eruption such as one at Yellowstone would disperse enormous quantities of ash and dust into the air. When this happened in 1815, the ash dissipated the sunlight. The following year there was no summer and crops worldwide failed. By some estimates, a single major eruption could trigger another major ice age. Considering how inhospitable the Earth's climate is, it is a miracle that life exists at all.

Besides volcanic eruptions, another major hazard Earth has to avoid is meteor impact such as the one that made the dinosaurs extinct. Such a collision would likely occur just moments after the meteor was sighted from the Earth's surface. There are an estimated 2,000 asteroids large enough to wipe out modern civilization and millions large enough to destroy cities. All have orbits too erratic to accurately predict. Even if humans knew about an impact a year in advance, there is little that we could do. Scientists estimate that the Earth has close brushes with various meteors two or three times per week.

Life Abounds in Space and On Earth

In spite of the generally inhospitable environment of space, it is likely that the cosmos teems with life. This is simply due to the law of averages. With over 140 million galaxies, many larger than the Milky Way, it is inevitable that some will have planets and that some of those planets will have intelligent life. Scientist Frank Drake placed the estimate at several million advanced civilizations within the Milky Way galaxy.

Bryson points out that it is extremely unlikely that Earth is being visited by intelligent aliens, despite the mind-boggling number of planets with life. He wryly notes that while every species probably has teenagers, the sheer distances involved in space travel make it virtually impossible that humans will ever connect with another intelligent civilization.

places as unlikely as deep ocean vents where temperatures are above 140?C.

The Earth was once home to hundreds of species of animals that weighed in excess of 2,000 pounds. All but five or six species were hunted until extinct by early man. Survivors include the elephant, giraffe, hippo, moose and the rhinoceros. Scientists estimate that of the world's original species, 95 percent of those in Australia, 75 percent of those in North America and 50 percent of those in Europe were driven to extinction by early hunters. This was especially prevalent in the Americas and in Australia, where many species had no natural fear of man.

Despite the enormous proliferation of life on Earth, in recent years species are becoming extinct at an unprecedented rate. Scientists estimate that as many as 1,000 species of plants and animals are becoming extinct every week. This sharp increase from two species per week is due solely to human interference.

Colorful Scientific Personalities

The stereotype of a scientist is an asocial, boring "math geek" with poor interpersonal skills who leads a mundane life. Bryson does much to dispel this myth by including brief but fascinating sketches detailing the personalities of some of the hundreds of remarkably gifted scientists in his book. Some of the scientists profiled seem interesting, charming, abrasive, or utterly insane, but few are boring.

Several of the scientists detailed were not good mathematicians. The aristocratic Percival Lowell suggested that there was a gas giant planet beyond Neptune, based on faulty calculations. He was right about the planet, Pluto, but wrong about it being a gas giant. The abrasive Frank Zwicky knew so little math that he left it to his collaborators to perform the calculations supporting his theories on supernovae. Cambridge's Ernest Rutherford, discoverer of the structure of the atom, often wrote equations on the board in class during lectures. Unable to solve the equations, Rutherford would blithely tell his students to work the math out for themselves.

Several brilliant scientists also supported preposterous theories that today's scientists know to be completely untrue. Fred Hoyle was a controversial cosmologist who claimed that a major museum was engaging in a hoax, completely without evidence. He gave the derisive name "The Big Bang" to a competitor's theory, which is now generally accepted. Yet, Hoyle was the first to identify nucleosynthesis inside supernovae as the process for creating heavy elements essential to life. Percival Lowell believed that an elaborate civilization on Mars had constructed complex irrigation canals. Lowell believed that he could see the canals through his telescope. By relating some of the oddities of various scientists, Bryson manages to make what is usually considered a dry topic lively and entertaining.

The personalities of scientists in the book seem to become more prosaic as the modern age approaches. This may be, in part, simply presentation. The public may know fewer of the eccentric details of various modern scientists. An alternate explanation would be that in the 18th and 19th centuries, science was not a conventional pursuit. For the most part, early scientists were wealthy gentlemen who chose to peer through microscopes, taste poisonous substances and spend years working on obscure theories while their cronies were playing cards, socializing and fox hunting. Today, science is far more likely to be the conventional career choice of an intelligent but normal student, rather than the eccentric behavior of a social misfit.

Style

Perspective

Bryson is a popular author who has written bestsellers on many topics, including travel and nature. He takes a cosmic perspective in this book, addressing everything from supernovae to the paired electrons of quantum physics.

Perhaps the only assumption that Bryson makes is that scientific inquiry is good. He assumes that the reader shares the belief that learning more about the universe, the Earth and human history will have positive results. Bryson clearly doesn't think that a belief in evolution and the scientific process is at odds with a belief in God. Bryson includes multiple references to God by scientists, which suggests that he believes in God himself. He does, however, reject a literal interpretation of the creation story in the Bible. Instead, Bryson quotes scientists who suggest that each "day" of creation in Genesis may encompass billions of years. Bryson doesn't overtly propound a belief in God and an atheist could overlook the references to Him.

In his rhapsodizing about the fortuitous accident of a universe with conditions perfect for human life, Bryson neglects to consider that there could well be other types of life equally suited to the conditions found in alternate universes. More probably, life evolved in its present form precisely because it was adapting to the specific gravity and physical restrictions of the current cosmos. Determinism is a form of inter-species chauvinism, the assumption that humans are the highest and best achievement of nature. It also assumes that all evolution was a series of orderly events leading to the pinnacle of achievement, modern civilization. Although Bryson pays lip service to the fallacy of determinism, he frequently engages in it.

Tone

Bryson's tone is informal and engaging as he clearly explains complicated scientific theories. For example, he refers to the entire creation of the cosmos as requiring less time than it takes to make a sandwich. By using such down-to-earth metaphors, Bryson makes it easier for non-scientists to relate to complex scientific concepts. The perspective is dispassionate, wide-ranging and objective. Bryson admits to being bored and mystified by science textbooks as a child. *A Short History of Nearly Everything* is his attempt to demystify science for the average reader. The book is essentially a brief overview of current thinking in the sciences. Bryson's reach includes cosmology, astronomy, geology, physics, paleontology, climatology, oceanography, quantum physics and biology.

The tone of *A Short History of Nearly Everything*, like the title, is clear, factual and light-hearted. The author is interested in science and strives to present it accurately, but he has a sense of humor about the topic as well. Bryson demonstrates this sense of humor by choosing examples of everyday objects to illustrate his points, like elephants and teacups. He compares the nucleus within an atom to a fly in a cathedral.

Part of this lighthearted tone involves Bryson's view of scientists. He clearly admires their intelligence and respects their work, but he is not awed by them. In fact, *A Short History of Nearly Everything* is as much a look at the incredible eccentricities and misbehavior of scientists over the centuries as it is an explanation of current scientific thought. Bryson details the exploits of Percival Lowell, Frank Zwicky, Agassiz and others carefully. He describes how Watson and Crick won a Nobel Prize by uncovering the structure of DNA, based on material stolen from a female colleague, Rosalind Franklin. Bryson includes telling details about the history and personal lives of scientists that bring them to life for the average reader.

Structure

Each chapter of the book deals with one area of scientific inquiry, in chronological format from its earliest history to its present understanding. The Big Bang essentially answers the question, "Where did the Universe come from?" while the final chapter, Good-Bye, details the various extinctions of plant and animal species caused by humans. This structure has the advantage of offering an overview of the topic, complete with outdated theories and current thinking. The reader can trace the history of thought on cosmology or evolution, from the earliest times to the present. At times, Bryson does seem to be sidetracked by colorful theories or interesting characters who had little real influence on scientific belief and advances.

The disadvantage to this method of organization is that there is little coordination between chapters. At times, the chapters read as if they were written by multiple authors For example, in the chapter on volcanoes Bryson suggests that a single, huge volcano eruption can ruin crops worldwide for more than a year. Since Bryson says elsewhere that a single unseasonably cool summer could cause an ice age, it follows that a single gigantic eruption could result in an ice age.

Yet, in the chapter on ice ages, Bryson never mentions this possibility. Instead, he discusses the theory that the Earth was once a giant snowball and was released from its frozen state by volcanic activity. This results in part from the fact that the two chapters stem from different scientific specialties(the study of volcanoes and climatology. Scientists within the two specialties have not made any effort to reconcile their theories, or even recognize the conflict. Still, it would be helpful if Bryson would admit that in some cases two theories that he is presenting are not compatible.

A similar contradiction occurs when Bryson claims in one chapter that a massive melting of the Antarctic snowcap caused by global warming would result in the flooding of coastal cities. In another chapter, he suggests that such melting would reduce the ocean's salinity, lowering the temperature at which the oceans freeze. This would increase the polar ice caps and likely cause another ice age. While it's not Bryson's task to reconcile the two scientific theories, it would be good to admit that a disagreement exists.

Quotes

"Of course, it is possible that alien beings travel billions of miles to amuse themselves by planting crop circles in Wiltshire or frightening the daylights out of some poor guy in a pickup truck on a lonely road in Arizona (they must have teenagers, after all), but it does seem unlikely." Part 1, Chapter 2, pg. 27

" 'I just seem to have a knack for memorizing star fields,'[Robert Evans] told me, with a frankly apologetic look, when I visited him and his wife, Elaine, in their picture-book bungalow on a tranquil edge of the village of Hazelbrook, out where Sydney finally ends and the boundless Australian bush begins. 'I'm not particularly good at other things,' he added. 'I don't remember names well.'

'Or where he's put things,' called Elaine from the kitchen." Part 1, Chapter 3, pg. 30

"The first [of Albert Einstein's 1905 papers] won its author a Nobel Prize and explained the nature of light (and also helped to make television possible, among other things). The second provided proof that atoms do indeed exist - a fact that had, surprisingly, been in some dispute. The third merely changed the world." Part 3, Chapter 8, pg. 120

"At one point he ran into a party of suspicious Crow Indians, but [Edward Drinker Cope] managed to win them over by repeatedly taking out and replacing his false teeth." Part 3, Chapter 7, pg. 92

"Physicists are notoriously scornful of scientists from other fields. When the wife of the great Austrian physicist Wolfgang Pauli left him for a chemist, he was staggered with disbelief. 'Had she taken up with a bullfighter I would have understood,' he remarked in wonder to a friend. 'But a chemist. . . '" Part 3, Chapter 9, pg. 137

"According to [Quantum theory], an electron moving between orbits would disappear from one and reappear instantaneously in another without visiting the space between. This idea - the famous 'quantum leap' - is of course utterly strange, but it was too good not to be true." Part 3, Chapter 9, pg. 143

"If this seems confusing, you may take some comfort in knowing that it was confusing to physicists, too. Overbye notes: 'Bohr once commented that a person who wasn't outraged on first hearing about quantum theory didn't understand what had been said.' Heisenberg, when asked how one could envision an atom, replied: 'Don't try.'" Part 3, Chapter 9, pg. 145

V CH SH ? ? sions, superstring theory enables physicists to pull together quantum laws and gravitational ones into one comparatively tidy package, but it also means that anything scientists say about the theory begins to sound worryingly like the sort of thoughts that would make you edge away if conveyed to you by a stranger on a park bench." Part 3, Chapter 11, pg. 167

". . . survivors [of an asteroid impact] would have no idea what was happening elsewhere or where to turn. It would hardly matter: As one commentator has put it, fleeing would mean 'selecting a slow death over a quick one. The death toll would be very little affected by any plausible relocation effort, since Earth's ability to support life would be universally diminished.'" Part 4, Chapter 14, pg. 209

" 'Wherever we go on Earth - even into what's seemed like the most hostile possible environments for life - as long as there is liquid water and some source of chemical energy we find life.'" NASA scientist Jay Bergstralh, Part 4, Chapter 15, pg. 235

" After a few days, the water in the flasks had turned green and yellow in a hearty broth of amino acids, fatty acids, sugars and other organic compounds. 'If God didn't do it this way,' observed Miller's delighted supervisor, the Nobel laureate Harold Urey, 'He missed a good bet.' " Part 5, Chapter 19, pg. 287

" 'The history of life,' wrote Gould,' is a story of massive removal followed by differentiation within a few surviving stocks, not the conventional tale of steadily increasing excellence, complexity, and diversity.' Evolutionary success, it appeared, was a lottery." Part 5, Chapter 21, pg. 327

"The most enigmatic character of all was [Rosalind] Franklin. In a severely unflattering portrait, Watson in *The Double Helix* depicted Franklin as a woman who was unreasonable, secretive, chronically uncooperative, and - this seemed especially to irritate him - almost willfully unsexy. He allowed that she 'was not unattractive and might have been quite stunning had she taken even a mild interest in clothes,' but in this she disappointed all expectations." Part 5, Chapter 26, pg. 405

"We know less about ourselves, curiously enough, than about almost any other line of hominids. It is odd indeed, as Tattersall notes, 'that the most recent major event in human evolution - the emergence of our own species - is perhaps the most obscure of all.'" Part 6, Chapter 29, pg. 457

"If this book has a lesson, it is that we are awfully lucky to be here - and by 'we' I mean every living thing. To attain any kind of life in this universe of ours appears to be quite an achievement. As humans, we are doubly lucky, of course: We enjoy not only the privilege of existence but also the singular ability to appreciate it and even, in a multitude of ways, to make it better. It is a talent we have only barely begun to grasp." Part 6, Chapter 30, pg. 478

Topics for Discussion

Should humans be worried about the possibility of a meteor striking the Earth, and the results of impact? Why or why not?

What is the most surprising discovery found in this book?

How many galaxies are there in the universe? Is it likely that some contain intelligent life? Explain your answer.

Do all of Bryson's conclusions make sense? Why or why not?

Just over 100 years ago, humans believed that there was only one galaxy, the Milky Way. About 200 years ago, many people believed that man could never fly in a balloon or an airplane because it was "unnatural." What amazing new discoveries should be expected by the year 2115?

Many of the scientists in this book had colorful personalities. Give an example.

Several of the 18th and 19th century scientists Bryson discusses were not good at mathematics at all. Is math more important for scientists now, or less important? Explain why.