A Short History of Nearly Everything

INTRODUCTION

BRIEF BIOGRAPHY OF BILL BRYSON

Bryson was born in Des Moines, Iowa. Both his parents were journalists, and they provided a strong foundation for Bryson's interest in writing. Bryson reflects on many of his childhood experiences in Iowa in his book *The Life and Times of the Thunderbolt Kid*. Despite his early interest in writing, Bryson dropped out of college, opting to travel in Europe instead, before settling in Britain and marrying a nurse named Cynthia Billen. The pair eventually returned to the United States for a brief spell so that Bryson could complete his degree, before permanently settling in Britain. Bryson worked as a journalist in the 1980s, rising to the rank of chief copy editor at *The Times* and national news editor at *The Independent*. Bryson then turned to writing memoir and nonfiction, centering on his personal experiences but interwoven with humor and cultural history. Notably, Bryson's *A Walk in the Woods* captures his experiences hiking the Appalachian Trail while offering a history of this trek as a cultural phenomenon. Bryson has won numerous awards for his writing. His international bestseller *A Short History of Nearly Everything* alone earned Bryson five prestigious international science writing prizes between 2005 and 2012. In 2006, Bryson was knighted in Britain for his contributions to literary culture, and the mayor of Des Moines declared October 21, 2006 Bill Bryson Day in honor of Bryson's depiction of his childhood in Iowa.

HISTORICAL CONTEXT

Bryson's focus is the history of scientific discovery in Europe and North America, centering on developments in science since the 1600s. Bryson effectively captures the advances of science after the Scientific Revolution, which occurred gradually between 1500 and 1600, though it is largely attributed to Copernicus's 1543 publication of *On the Revolutions of the Heavenly Spheres* and culminates in Newton's 1688 *Principia Mathematica*. Scholarship during this time shifts from a God-centered worldview advanced by the Catholic Church to a human-centered worldview based on observable facts about the world, giving rise to modern science and the formation of the scientific disciplines. Bryson often alludes to tensions between religious values and scientific values in *A Short History of Nearly Everything*, emphasizing how often religious ideas can hold up the task of scientific discovery, despite the shift in authority toward scientific over religious worldviews that occurred after the Scientific Revolution.

RELATED LITERARY WORKS

In *A Short History of Nearly Everything*, Bryson switches from his usual memoir genre to instead focus on scientific discovery. He discusses hundreds of scientific books and articles as he recounts a history of scientific thought ranging back to the 1600s. These include canonical texts like Isaac Newton's *Principia Mathematica* (1686), Charles Darwin's *On the Origin of Species* (1859), Richard Dawkins's *The Blind Watchmaker* (1988), and Charles Lyell's *The Principles of Geology* (1830–1833). Bryson also addresses scientific books that get overlooked because they are so poorly-written that the ideas are hard to follow, calling out James Hutton's *Theory of Earth* (1788) in particular. Bryson was inspired by writers who strive to write engaging science, especially the "godlike" Richard Feynman (who wrote *Six Easy Pieces*) and Richard Fortey (who wrote the "wry" and "splendid" *Life: An Unauthorized Biography*), both published in 1998. Other influences include Timothy Ferris's 1998 books *Coming of Age in the Milky Way* and *Guarding Earth from Interplanetary Peril*, and Tim Flannery's 2001 book *A Gap in Nature: Discovering the World's Extinct Animals*. Other writers who—like Bryson—offer popular takes on scientific research include David Attenborough, who addresses life's biodiversity on Earth in his 1984 book *The Living Planet: A Portrait of the Earth*, and Richard Dawkins, who offers a genetic take on evolution in *The Selfish Gene*. Like Bryson, Dawkins favors the use of metaphors, anecdotes, and engaging prose over technical writing.

KEY FACTS

- **Full Title:** A Short History of Nearly Everything
- **When Written:** 2002–2005
- **Where Written:** Surrey, England
- **When Published:** 2005
- **Literary Period:** Contemporary
- **Genre:** Popular Science; Nonfiction
- **Climax:** Bryson argues that life in the universe is extremely rare and precarious, and that humans take grave risks in treating our planet carelessly.
- **Point of View:** First Person

EXTRA CREDIT

Happy Accidents. Bryson emphasizes that many scientific discoveries happen by accident, including the discoveries of phosphorous (in glowing urine), radioactivity (from a lump of uranium left on a photographic plate), and the particle collider (which was supposed to be a cloud machine). Bryson aims to show that science has as much to do with luck and circumstance as it does with genius thinkers and formulas.

Funny Stories. Bryson often infuses his writing with quirky, irreverent, humanizing biographical details that aren't typical in science writing. Examples include Isaac Newton's odd affection for doing bizarre things out of sheer curiosity (such as poking needles into his eyes or staring into the sun until he can't see), the Reverend William Buckland's culinary desire to taste every animal on Earth, and Humphry Davy's recreational nitrous oxide (laughing gas) habit.

PLOT SUMMARY

Author Bill Bryson begins *A Short History of Nearly Everything* by saying that he's glad the reader can join him, especially because the reader—like every other living being—only exists because of a long chain of history, starting with atoms and resulting in complex life. To be alive at all is the result of an extreme amount of "biological good fortune," since 99.99 percent of species go extinct, and the existence of all species depends on a very specific history of good timing and good luck.

Bryson also marvels at how scientists learn the things they know, and he wonders why so much science writing depicts the history of scientific discovery as abstract, dull, and technical. Bryson explains that his motivation for writing this book arose from his realization that he knows very little science himself, because he found most science textbooks boring and inaccessible during his education. His aim is to see if it's possible to write science in a way that makes the reader marvel at the history of life on Earth and to become more curious about the task of scientific inquiry.

In Part 1, "Lost in the Cosmos," Bryson explains how a universe like ours is formed: all of the matter in existence is compressed into a tiny, dimensionless area and then undergoes a rapid expansion (or "Big Bang"), creating all the space that exists as it spreads out. The Big Bang theory, along with "inflation theory" (the notion that the universe is expanding), were formulated in the 20th century. Bryson emphasizes how the conditions that formed our universe were extraordinary: if one small factor had been different, life as we know it would never have come about.

Bryson goes on to emphasize just how vast the universe is and how distant Earth is from other celestial bodies: Pluto, for instance, is billions of miles away, and it remains elusive to this day. There are hundreds of billions of other galaxies in addition to the hundreds of billions of stars in the Milky Way. Bryson also notes that what we perceive when we stargaze is actually an image of the past since the vastness of the cosmos means it takes light years (trillions of kilometers) for the light from stars to reach Earth. Bryson then focuses on how our solar system was formed over four billion years ago through a chance gathering of an enormous gas cloud (the sun) and tiny grains of dust colliding until they formed planets. Earth's carbon dioxide-containing atmosphere created a "greenhouse effect" which concentrated the sun's rays and warmed the planet. These conditions established an environment suitable for life, which began 500 million years later. Four billion years after organic compounds first emerged on Earth, life as we know it today exists.

Bryson begins Part 2, "The Size of the Earth," with Newton's 1688 discovery of the force of gravity and the universal laws of motion. In the 1700s, Newton's discoveries trigger several challenging expeditions around the globe to determine Earth's size, precise shape, mass, and location in the solar system. Bryson goes on to discuss geology, which originates in the 1700s with James Hutton. Hutton suspects that mountains are formed by land masses crashing into each other. He's correct, but he writes so obtusely that his claims are overlooked because nobody can understand him. Nonetheless, interest in geology starts to pick up, and "stone breaking" even becomes a popular hobby among affluent 19th-century men. They dress up and venture into the countryside to dig up stones. Consequently, people start digging up dinosaur bones, although it takes a while for scientists to figure out what they are and to realize that species—like the dinosaurs—go extinct.

Bryson looks at chemistry next. He praises Mendeleyev's elegant design for the periodic table (and Mendeleyev's mother for hitchhiking 4,000 miles across Russia to make sure her son got an education). He also emphasizes Marie Curie's singular achievement as the only person in history to win Nobel Prizes in Physics (for her work on radioactivity) and Chemistry (for her discovery of new elements including polonium).

In Part 3, "A New Age Dawns," Bryson wryly notes that by 1900, scientists think they've figured out all there is to know about the physical world, yet their picture of reality is about to be radically altered. In 1905, Einstein formulates "relativity theory," arguing that space and time are not static but relative to the observer. Around the same time, Planck develops "quantum theory," arguing that light doesn't travel in a continuous wave, but in packets called "quanta." This means that light—perplexingly—acts like both a wave *and* an object. Atomic scientists like Rutherford also learn that atoms contain mostly empty space, and Bohr realizes that electrons jump around (or appear and disappear) in this space, dubbing the phenomenon "quantum leap."

Bryson then addresses 1930s astronomy. At the time, women don't have many opportunities beyond working as support staff who catalog stars. Nonetheless, one of these women, Henrietta Swan Leavitt (who only has access to smudged photographic images), invents "standard candles," an "ingenious" way to measure relative distances between galaxies. Leavitt's invention allows Hubble to calculate that the universe is comprised of billions of galaxies beyond our own, meaning it's far vaster than anyone ever imagined. Bryson also discusses the damaging effects of pollution, focusing on atmospheric lead, CFCs, and the hole in Earth's ozone layer, which now is unable to prevent deadly radiation from space leaking into the atmosphere.

Meanwhile, scientists discover that subatomic particles operate under completely different scientific laws than everything else in the universe. Bryson is perplexed by the highly speculative and counterintuitive theories that scientists formulate in attempts to make sense of the subatomic world. "Superstring theory," for example, suggests that tiny particles called "quarks" oscillate in 11 dimensions (seven of which are inaccessible to humans). Bryson then shifts his focus to "continental drift" theorists who correctly claim that Earth's land masses are in motion, that collisions between them create mountains, and that Earth is molten below its crust.

In Part 4, "Dangerous Planet," Bryson focuses on how precarious life on Earth is. In the 1990s, scientists learn that the dinosaurs were obliterated 65 million years ago by a massive asteroid collision known as the "KT Impact." Bryson stresses that several meteors large enough to wipe out life on Earth regularly cross Earth's orbit, meaning that we face an ongoing threat of extinction. Bryson then addresses natural disasters. Scientists know very little about the internal seismic activity within Earth that triggers earthquakes. So far, humans have only been able to dig a few miles into Earth's 3,950-mile-deep crust. Bryson also explains that Yellowstone National Park is an active "supervolcano" that is already overdue for its next eruption, which will destroy most of the Americas. Bryson stresses that humans should not be misguided by the relative tranquility we've experienced on Earth's surface thus far, because things could change in an instant.

In Part 5, "The Stuff of Life," Bryson explains that knowledge about deep oceans and the atmosphere at high altitudes is limited to testimonies from a handful of adventurous deep-sea divers and experimental balloon fliers until the 1950s. Since then, scientists have learned about Earth's layered atmosphere and that ocean life is far more abundant and diverse than anyone previously assumed. Bryson worries that routinely dumping toxic waste into the oceans (like many nations do) is irreparably damaging a large part of the delicately-balanced ecosystem that keeps humans alive. Bryson also highlights that humans can't survive for long in deep water or high altitudes—we are essentially "ground hugging beings" who can only thrive in a small sliver of Earth's environment.

Bryson moves on to address the rise of life, dubbed the "Big Birth," beginning with microbes that got life going about 4 million years ago that evolved into plant life, sea life, and land life—including dinosaurs and mammals. Bryson emphasizes that life is a wondrous phenomenon and that human life evolves largely out of blind luck and timely accidents. Bryson then highlights that the present-day world is full of beguiling biodiversity, and scientists only know about a small fraction of Earth's plant and animal species—especially when it comes to underexplored environments like rainforests and deep oceans.

Turning to cellular life, Bryson explains that the discovery of cells prompts scientists to think about heredity in the 1800s. At the same time, Darwin develops his "theory of evolution." Darwin argues that human life evolved out of simpler organisms through a process of "natural selection," meaning that the animals best adapted to their environment survive to reproduce and pass on those traits. Darwin's fear of religious persecution leads him to lock his notes away for almost 15 years before making his theory public in 1859. In the 1930s, scientists combine Darwin's theory with research on heredity and formulate the "modern synthesis," which posits that genes are responsible for inherited traits, and they are the mechanism by which life evolves.

In Part 6, "The Road to Us," Bryson explains that scientists think ice ages are caused by a combination of Earth wobbling on its axis and cool summers that fail to melt sufficient surface ice on the planet. Paradoxically, Bryson explains, it's unclear to scientists whether increased atmospheric carbon dioxide from human pollution will trigger a harsh ice age or harsh global warming. To Bryson, one thing *is* certain: we are living on a "knife edge."

Bryson then looks into the dawn of humanity around 100,000 years ago, covering bipeds (beings that walk on two limbs), the missing link between apes and humans, and the evolution of hominids, including Neanderthals and Homo sapiens (humans). Bryson stresses that there is an astounding lack of evidence about this period in history because there are so few fossils available for analysis. Scientists know very little about the evolution of apes to humans, and they are limited at best to speculation. Bryson concludes that scientists are only at the beginning of this journey, and they face countless mysteries when it comes to learning about early hominids.

Bryson's closes the book with a cautionary tale for the reader that focuses on the tremendous amount of extinctions caused by human activity, which Bryson describes as cruel, foolish, and careless. Bryson ends his story by urging the reader to appreciate how rare and precious life is, and how humans should take more care not to endanger our own survival or the survival of other species. For Bryson, human existence has thus far relied on luck, but in the future, it's going to demand a lot more care and a lot less recklessness.

CHARACTERS

MAJOR CHARACTERS

Bill Bryson – Bryson is the author and sole narrator of the story. Bryson feels that he knows very little about science, primarily because he found science textbooks so dull and technical as a child. To remedy this, he starts learning about the history of scientific discovery because he's curious about how scientists come to know what they know. The result is the narrative he tells in *A Short History of Everything*. In the book, Bryson explores scientific discovery in a range of scientific areas, but especially in physics, biology, chemistry, geology, meteorology, astronomy, oceanography, and paleontology. To make this story more engaging for laypeople, Bryson invokes frequent humorous biographical anecdotes about the scientists he addresses, and he avoids technical jargon, favoring visual metaphors instead. His aim is to show that scientific discovery is in its very early stages (despite how often scientists declare otherwise), as well as to show that clear, accessible expression and classification are essential to the scientific endeavor. Bryson also aims to demonstrate how scientific progress is hindered by prejudices like patriarchal values and religious biases. Ultimately, Bryson wants the reader to understand that life is a rare, precious, and precarious thing that is worthy of awe, profound respect, and care.

Albert Einstein – Einstein was a famous German-Swiss scientist who formulated relativity theory in 1905. He figured out that the speed of light is constant in the universe, that all mass can be converted into energy, that space and time aren't separate but interwoven, and that the universe is not static but either expanding or contracting.

MINOR CHARACTERS

Arno Penzias – Penzias is an astronomer who, along with Robert Wilson, detected cosmic radiation from the Big Bang in 1965 and won a Nobel Prize in Physics in 1978.

Robert Wilson – Wilson is an astronomer who, along with Arno Penzias, detected cosmic radiation from the Big Bang in 1965 and won a Nobel Prize in Physics in 1978.

Robert Dicke – Dicke is an astronomer at Princeton University who inspired and explained many discoveries about the universe in the 1960s, including cosmic radiation from the Big Bang and the idea of an expanding universe.

Robert Guth – Guth is an astronomer who formulated the "inflation theory" of the universe.

Martin Rees – Rees is a British astronomer who analogized the likelihood of life to finding a suit that fits in a department store.

James Christy – Christy is an astronomer who discovered Pluto's moon in 1978.

Percival Lowell – Lowell is an astronomer who predicted Pluto's existence.

Clyde Tombaugh – Tombaugh is an astronomer who discovered Pluto.

Frank Drake – Drake is an astronomer who calculated the likelihood of alien civilizations in the universe.

Reverend Robert Evans – Evans is an amateur astronomer who spots supernovae using his backyard telescope.

Fritz Zwicky – Zwicky was a widely-disliked Bulgarian astronomer who coined the term "supernova."

Oppenheimer – Oppenheimer was a scientist who popularizes the idea of neutron stars.

John Thorsten – Thorsten is an astronomer who explains to Bill Bryson that there isn't a star large enough to annihilate life on Earth by collapsing into a supernova.

Fred Hoyle – Hoyle was a controversial astronomer who showed that supernova energy creates elemental matter.

W. A. Fowler – Fowler collaborated with Fred Hoyle and received a Nobel Prize for supernova research.

Pierre Bouguer – Bouguer was a French hydrologist who led a disaster-plagued, decade-long expedition to the Equator with Charles Marie la Condamine to calculate Earth's circumference in 1735.

Charles Marie la Condamine – La Condamine was a French soldier-mathematician who led a disaster-plagued decade-long expedition to the Equator with Pierre Bouguer to calculate Earth's circumference in 1735.

Edmond Halley – Halley was a prolific mathematician, inventor, and scientist during the 17th and 18th centuries who pushed Isaac Newton into researching motion and gravity. Halley discovered the eponymous Halley's Comet.

Isaac Newton – Newton was a quirky and eccentric mathematician in the 17th and 18th centuries who formulated the three laws of motion and discovered the force of gravity. He also argued that Earth is not a perfect sphere, but slightly squashed at the poles.

Robert Norwood – Norwood was a British sea navigator and scientist who calculated the distance of a degree (originating at Earth's core) as 110.72km wide (on the surface) in 1637. He burned his subsequent research on trigonometry, fearing religious persecution.

Jean Picard – Picard was a French astronomer who calculated the distance of a degree (originating at Earth's core) as 110.46km wide (on the surface) in 1669.

Giovanni and Jacques Cassini – Giovanni and Jacques Cassini were a father-son team who (incorrectly) disputed Newton's claim that Earth is squashed at the poles.

Nevile Maskelyne – Maskelyne was a British scientist who attempted to measure the transit of Venus from St. Helena in 1761. He surveyed Schiehallion mountain in 1774 to test Newton's hypothesis that a plumb bomb suspended near a mountain will tilt toward it.

Charles Mason – Mason was a British scientist who unsuccessfully attempted to measure the transit of Venus from Sumatra in 1761. Along with Jeremiah Dixon, he plotted the Mason-Dixon line.

Jeremiah Dixon – Dixon was a British scientist who unsuccessfully attempted to measure the transit of Venus from

Sumatra in 1761. Along with Charles Mason, he plotted the Mason-Dixon line.

Jeanne Chappe – Chappe was a French scientist who unsuccessfully attempted to measure the transit of Venus from Siberia in 1761.

Guillame Le Gentil – Le Gentil was a French scientist who unsuccessfully attempted to measure the transit of Venus from India in 1761 and 1769.

James Cook – Cook was a British explorer who successfully measured the transit of Venus from Tahiti in 1769, before claiming Australia as a British colony.

Joseph Lalande – Lalande was a French astronomer who calculated Earth's distance from the sun (150 million km) using James Cook's measurements from the 1769 transit of Venus.

Charles Hutton – Hutton was a British mathematician who used Nevil Maskelyne's 1774 survey of Schiehallion mountain to calculate the mass of Earth, the sun, and the other planets in the solar system.

Henry Cavendish – Cavendish was a shy British scientist who discovered numerous scientific laws but didn't publish his findings. He accurately calculated Earth's mass (six billion trillion metric tons) in 1797 using a machine left to him by John Michell.

John Michell – Michell was a British parson who invented a machine for calculating Earth's mass. Henry Cavendish went on to utilize this machine for its intended purpose.

James Hutton – Hutton was a Scottish farmer and scientist who invented geology in the 1700s. He was a notoriously indecipherable writer.

John Playfair – Playfair was a British mathematician who summarized James Hutton's ideas in more elegant prose in 1802.

Roderich Murchison – Murchison was a geologist who published the esoteric but bestselling book *The Silarium System* in 1839.

Charles Lyell – Lyell is widely considered to be the father of modern geology.

Reverend William Buckland – Buckland was the eccentric professor of Charles Lyell.

Charles Darwin – Darwin developed the theory of evolution. He was profoundly influenced by Charles Lyell's work, and he briefly postulated that parts of Earth were 300,662,400 years old.

Archbishop James Ussher – Ussher was a scholar and church leader who argued that Earth was created "at midday on October 23, 4004 B.C."

Compte de Buffon – Buffon was a French naturalist and mathematician who argued that Earth was 75,000-168,000 years old and that the "New World" was a wasteland with shriveled animals and disfigured natives.

Lord Kelvin – Kelvin was a prolific scientist who devised the scale of absolute temperature and the second law of thermodynamics and patented modern refrigeration. Kelvin severely underestimated Earth's age.

Dr. Caspar Wistar – Dr. Wistar analyzed the first dinosaur bone ever discovered, thinking it an uninteresting relic.

Thomas Jefferson – Jefferson was the third president of the United States, serving from 1801–1809. He commissioned numerous expeditions westward to disprove Buffon's claims about the "New World."

Willian Smith – Smith was a mining surveyor who deduced that fossil age is related to rock strata.

Mary Anning – Anning was a preteen girl who excavated and sold "sea monster" fossils in Dorset from 1812, many of which are now in London's Natural History Museum.

Gideon Algernon Mantell – Mantell was a country doctor and amateur fossil hunter in the 19th century.

Mrs. Mantell – Mrs. Mantell is the amateur fossil hunter Gideon Algernon Mantell's wife. She discovered a Megalosaurus tooth fossil in Sussex in 1822.

Richard Owen – Owen was a diabolical and "sinister" paleontologist who claimed credit for many other amateurs' fossil discoveries (including many of Gideon Algernon Mantell's). However, he also revolutionized museum culture by allowing working-class people to access the Natural History Museum in the 1800s.

Edward Drinker Cope – Cope was an American paleontologist whose rivalry with Othniel Charles March resulted in the collective excavation of almost 140 species of dinosaur bones in the 1800s.

Othniel Charles March – March was an American paleontologist whose rivalry with Edward Drinker Cope resulted in the collective excavation of almost 140 species of dinosaur bones in the 1800s.

Ernest Rutherford – Rutherford was a New Zealand farm boy who grew up to discover the concept of radioactive half-life in the early 1900s, thus providing concrete evidence that Earth was at least several hundred million years old. He also determined the structure of the atom.

Henning Brand – Brand was a German pharmacist and alchemist who accidentally discovered phosphorus in 1675 while attempting to distill urine into gold.

Karl Scheele – Scheele was a Swedish chemist who devised a method for mass-producing phosphorous in the 1750s.

Antoine-Lauren Lavoisier – Lavoisier was a French nobleman who devised the system for naming elements. He was executed by guillotine during the French Revolution.

Madame Lavoisier – Madame Lavoisier was Antoine-Lauren

Lavoisier's wife and collaborator.

Jean-Paul Marat – Marat was a scientist who had Lavoisier deposed during the French Revolution.

Count von Rumford – Von Rumford was an American-born British physicist who set up the British Institute.

Humphry Davy – Davy was a professor of chemistry at the British Institute who discovered numerous elements.

J. J. Berzelius – Berzelius was a Swedish scientist who standardized the symbolization of elements.

John Newlands – Newlands was an amateur chemist who attempted to devise a periodic table modeled on the octaves of the musical scale in the 1860s.

Dmitri Ivanovich Mendeleyev – Mendeleyev was a Russian chemist who developed the periodic table of elements in 1869, inspired by the card game solitaire.

Mendeleyev's mother – Dmitri Mendeleyev's mother hitchhiked 4,000 miles to make sure her son could get an education.

Marie Curie – Curie was a prolific French scientist who coined the term "radioactive" and became the only person in history to win Nobel Prizes in both Physics (1903) and Chemistry (1911).

Max Planck – Planck was a German scientist who formulated quantum theory in 1900.

Vesto Slipher – Slipher was an American astronomer who noticed the red shift effect (which proves that distant galaxies are moving away from ours).

Henrietta Swan Leavitt – Leavitt was an observatory clerk who realized that pulsating red dwarf stars can function as "standard candles" against which to measure the relative distance of other stars.

Edwin Hubble – Hubble was an American astronomer who combined Vesto Slipher's red shift and Henrietta Swan Leavitt's standard candle measure to discover that the universe is full of galaxies that are moving away from ours with increasing velocity (meaning that the universe is expanding).

George Lemaitre – Lemaitre was a Belgian theologian who realized Edwin Hubble's findings proved that the universe expanded from a single starting point, anticipating the Big Bang theory.

John Dalton – Dalton was an English chemist who hypothesized in 1808 that elementary particles can't be destroyed.

Niels Bohr – Bohr was a physicist who realized in 1913 that electrons appear to jump in space. He dubbed the phenomenon "quantum leap."

Werner Heisenberg – Heisenberg was a physicist who developed an "uncertainty principle" to explain electron behavior.

Robert Midgley Jr. – Midgley was a commercial engineer who developed chlorofluorocarbons (CFCs). He discovered that adding lead to gasoline reduced engine shudder, resulting in global pollution on a massive scale that burns a hole in the ozone layer and drastically increases atmospheric lead.

William Libby – Libby was an American chemist who invented radiocarbon dating for bones.

Clair Patterson – Patterson was an American geochemist who dated Earth at 4,550 million years old (the current standing estimate) by measuring the half-life of uranium in meteorites.

C. T. R. Wilson – Wilson was a Scottish physicist who accidentally invented the particle detector while trying to build a cloud machine.

Carl Sagan – Carl Sagan was a scientist and popular author who suggested that electrons might contain mini-universes of their own.

Murray Gell-Man – Gell-Man was an American physicist who hypothesized that subatomic particles were made of "quarks."

Charles Hapgood – Hapgood was a college professor who argued in 1955 that continental drift was a hoax.

Alfred Wegener – Wegener was a German scientist who hypothesized in 1912 that Earth's continents began as one land mass that he named "Pangaea."

Arthur Holmes – Holmes was a British geologist who realized that radioactive currents within Earth could cause continental drift.

Harry Hess – Hess was a geologist and U.S. Navy officer who discovered during World War II that the ocean floor wasn't sedimented, but mountainous.

Patrick Blackett – Blackett was a British physicist who researched iron particles in rock to prove continental drift.

S. K. Runcorn – Runcorn was a British physicist who researched iron particles in rock to prove continental drift.

Drummond Matthews – Matthews was a British marine geologist and geophysicist who postulated the theory of plate tectonics.

Fred Vine – Vine was a British marine geologist and geophysicist who postulated the theory of plate tectonics.

Eugene Shoemaker – Shoemaker was an American geologist who, using anomalous soil samples, discovered that an Arizona crater resulted from a meteor. This prompted subsequent asteroid impact research.

David Levy – Levy is an amateur astronomer who studied asteroids alongside Shoemaker.

Walter Alvarez – Walter Alvarez is a UC Berkeley professor who in the 1970s discovered the KT boundary (a thin layer of clay capturing asteroid debris that wiped out the dinosaurs 65 million years ago).

Luis Alvarez – Luis Alvarez was Walter Alvarez's father. He was a Nobel Prize-winning nuclear physicist.

Frank Asaro – Asaro was a UC Berkeley chemist who tested the clay in Walter Alvarez's sample, confirming that it was from space.

Ray Anderson – Anderson incorrectly suggested that the Manson Crater was responsible for the extinction of the dinosaurs.

Brian Witzke – Witzke incorrectly suggested that the Manson Crater was responsible for the extinction of the dinosaurs.

Alan Hildebrand – Hildebrand discovered the impact site responsible for the extinction of the dinosaurs in Mexico.

Tom Gehrels – Gehrels was an American astrophysicist and asteroid hunter.

Mike Voorhies – Voorhies was a geologist who discovered preserved bones in a swamp in Nebraska in 1971, indicating evidence of a volcanic eruption.

Bill Bonnichsen – Bonnichsen was a geologist who matched bone samples in Nebraska to a volcanic eruption in Idaho.

R. D. Oldham – Oldham was a geologist who hypothesized that Earth has a solid core from angles of rebounding seismic waves.

Andrija Mohorovičić – Mohorovičić was a seismologist who discovered that seismic shock waves rebound off something in Earth's interior between the crust and the core.

Inge Lehman – Lehman was a Danish seismologist who hypothesized that Earth has two cores.

Charles Richter – Richter was a scientist who devised the Richter scale along with Beno Gutenberg.

Beno Gutenberg – Gutenberg was a seismologist who devised the Richter scale along with Charles Richter.

Bob Christiansen – Christiansen is a geologist who worked for the United States Geological Survey. In the 1960s, he realized that Yellowstone National Park is a supervolcano.

Paul Doss – Doss is Yellowstone National Park's geologist.

Thomas and Louise Brock – Thomas and Louise Brock are a husband-and-wife scientist team who discovered microbes living in hot, acidic matter in Yellowstone National Park in 1965, which defied prior knowledge about which conditions are hospitable to life.

Philippe Teisserenc de Bort – De Bort was a French meteorologist who discovered the stratosphere while traveling by air balloon.

Gustav-Gaspard de Coriolis – De Coriolis was a French engineer and mathematician who discovered the mechanism that causes wind (now named the "Coriolis effect") in 1835.

Daniel Gabriel Fahrenheit – Fahrenheit was a Dutch instrument-maker who invented the first accurate thermometer and devised the Fahrenheit scale in 1717.

Anders Celsius – Celsius was a Swedish scientist who devised the Celsius scale in 1742.

Luke Howard – Howard was a British scientist who named the cloud types.

Edward Forbes – Forbes was a British naturalist who incorrectly concluded that marine life can't live below 2,000 feet because of a lack of light.

Charles William Beebe – Beebe was a deep sea diver who, along with Otis Barton, invented an early diving vessel in the 1930s.

Otis Barton – Barton was a deep sea diver who, along with Charles William Beebe, invented an early diving vessel in the 1930s.

Auguste and Jacques Piccard – August and Jacques Piccard were a father-and-son diving team who devised a deep-sea vessel and descended to the lowest point on Earth, the Mariana Trench, in the 1950s. The feat has never been repeated by anyone else.

Stanley Miller – Miller was a graduate student who attempted to replicate the origins of life on Earth. In 1953, he showed that methane, ammonia, and hydrogen sulphide mixed with water and electricity create simple organic compounds.

Richard Dawkins – Dawkins is a scientist and popular author who advanced the "gene's eye view" of evolution and discusses the origins of life on Earth.

Victoria Bennett – Bennett is scientist who surveys ancient rocks for organic compounds to deduce the conditions in which life on Earth started.

Russell Vreeland – Vreeland is a scientist who claimed to resuscitate 250-million-year-old bacteria.

Ernst Haeckel – Haeckel was a 19th-century scientist who argued that bacteria needed to be added as a third category of living organism, in addition to plants and animals.

R. H. Whittaker – Whittaker was a scientist who proposed dividing life into five categories of organisms in 1969.

Carl Woese – Woese was a scientist who proposed dividing life into 23 categories of organism (of which 19 are microbial) in 1976.

William Stewart – Stewart was a United States Surgeon General who, in the early 1960s, wrongly claimed that infectious disease would soon be completely eradicated due to the efficacy of penicillin.

Barry Marshall – Marshall is an Australian doctor who discovered in 1983 that deadly stomach ulcers and many stomach cancers are caused by bacteria.

Richard Fortey – Fortey is a paleontologist whose favorite ancient fossil is the "trilobite" (which lived long before the dinosaurs).

Charles Doolittle Walcott – Walcott was a paleontologist who discovered the Burgess Shale fossil bed in Canada in 1909, which contained 500-million-year-old fossils from a period in history known as the Cambrian explosion.

Simon Conway Morris – Morris is an American scientist. As a graduate student, he studied the Burgess Shale fossils, which suggested that early life was—curiously—more complex than initially assumed.

Steven Jay Gould – Gould was an American scientist who suggested that the Cambrian explosion was a "trial and error" period that foreshadowed evolution.

John Mason – Mason was an English schoolboy who discovered a 600-million-year-old Precambrian era flatworm fossil.

Erik Jarvik – Jarvik was an eccentric Swedish scientist who locked away a fossil in 1948 that scientists mistakenly thought might be the ancestor fish that gave rise to human life.

Len Ellis – Ellis a scientist who curates mosses in London's Natural History Museum.

Joseph Banks – Banks was a British botanist who collected 30,000 plant specimens in the 1700s.

Carl Linné – Linné was an eccentric Swedish botanist who simplified the botanic naming system.

Antoni van Leeuwenhoek – Van Leeuwenhoek was a Dutch linen draper who invented the world's most powerful microscope thus far in the 18th century.

Nicolaus Hartsoecker – Hartsoecker was a scientist who thought that sperm cells were tiny preformed people.

Louis Pasteur – Pasteur was a famed scientist who realized that cells are essential to all life. He also made crucial discoveries in vaccination and pasteurization, which revolutionized the field of disease prevention.

Robert FitzRoy – FitzRoy was the captain of the HMS *Beagle*, a Royal Navy ship on which Charles Darwin traveled around the world before formulating his theory of evolution.

Herbert Spencer – Spencer was an evolutionary scientist who coined the phrase "survival of the fittest."

Alfred Russel Wallace – Wallace was an evolutionary scientist.

T. H. Huxley – Huxley was a critic of evolutionary theory.

William Paley – Paley was a theologian who argued for creationism in his 1802 "argument from design."

Gregor Mendel – Mendel was a monk who crossbred peas to examine heredity.

Johan Friedrich Miescher – Miescher was a Swiss scientist who discovered DNA in 1869.

Thomas Hunt Morgan – Morgan was a scientist who investigated chromosomes by breeding fruit flies.

Oswald Avery – Avery was a scientist who cross-bred bacteria to show that DNA is the active agent in heredity.

Maurice Wilkins – Wilkins was a scientist who discovered the structure of DNA.

Rosalind Franklin – Franklin was a scientist who discovered the structure of DNA despite facing substantive sexism in her work environment.

Francis Crick – Crick was a scientist who discovered the structure of DNA.

James Watson – Watson was a scientist who discovered the structure of DNA.

Karl Schimper – Schimper was a botanist who coined the term "ice age" in 1837.

Louis Agassiz – Agassiz was a scientist who formulated the theory of ice ages in the 19th century.

James Croll – Croll was a janitor who correctly hypothesized that ice ages are triggered by Earth wobbling on its axis.

Milutin Milankovitch – Milankovitch was a scientist who improved on James Croll's calculations about Earth's ice ages.

Wladimir Köppen – Köppen was a scientist who correctly argued that cool summers trigger ice ages.

Marie Eugène François Thomas Dubois – Dubois was a Dutch scientist who discovered early hominid fossils in Sumatra.

Raymond Dart – Dart was an anatomist who analyzed early hominid fossils.

F. Clark Howell – Howell was a scientist who tried to simplify the hominid classification system.

Lucy – Lucy was an early hominid whose fossilized remains were discovered in 1974 and dated to over 3 million years old.

Ian Tattersall – Tattersall is a scientist who studies early hominid fossils.

Matt Ridley – Ridley is a science writer who studies Neanderthals.

Alan Walker – Walker was a scientist who described Homo erectus as a fearsome creature.

Richard Leakey – Leakey is a scientist who discovered a near-complete early hominid skeleton.

Alan Thorne – Thorne was a scientist who posited that people from different regions of the world have different hominid ancestor species (the multiregional hypothesis).

Carleton Coon – Coon was a scientist who controversially argued that Alan Thorne's multiregional hypothesis implied that some races are innately superior to others.

Rosalind Harding – Harding is a population geneticist who thinks that early hominid research is in its infancy.

Jillani Ngalli – Ngalli is Bill Bryson's guide while Bryson is exploring ancient tool beds in Kenya.

Tim Flannery – Flannery is an Australian naturalist who studies extinct species.

Lionel Walter Rothschild – Rothschild was an independent collector of rare taxidermy animals who inadvertently rendered some species extinct.

Hugh Canning – Canning was an independent collector of rare taxidermy animals who inadvertently rendered some species extinct.

Alanson Bryan – Bryan was a collector who killed the last black mamos bird.

William Shakespeare – Shakespeare was an 16th- and 17th-century English playwright, widely regarded as the greatest writer in the English language.

Ludwig van Beethoven – Beethoven was a famous 18th- and 19th-century German classical composer.

Genghis Khan – Khan was a notorious military conqueror and the Emperor of the Mongol Empire from 1206–1227.

THEMES

In LitCharts literature guides, each theme gets its own color-coded icon. These icons make it easy to track where the themes occur most prominently throughout the work. If you don't have a color printer, you can still use the icons to track themes in black and white.

SCIENCE, DISCOVERY, AND MYSTERY

In *A Short History of Nearly Everything*, author Bill Bryson claims that scientists often believe they have figured out all there is to know about a particular topic before realizing they are wrong. Most scientific discoveries, in fact, imply that we only know a tiny fraction of what there is to know, which prompts Bryson to conclude that the more humans learn—about the universe, life on Earth, and the planet itself—the more we realize how little we know. The scientific endeavor, thus, is only in its infancy. Bryson suggests that the universe is fraught with countless mysteries that take generations to solve. Such mysteries will likely occupy scientists for as long humans exist, meaning there will always be a need for scientific discovery.

Bryson emphasizes that humans have only discovered a fraction of the physical components of our world, which means that the project of scientific discovery is only just getting started. Bryson argues that geological scientists are only at the beginning of their journey because scientists know "very little" about what goes on underneath Earth's crust, and most of their assumptions about Earth's interior continue to be proven false as more discoveries are made. Bryson explains that thus far, humans have only been able to penetrate 12,262 meters (approximately 12 kilometers) into Earth's crust, which scientists estimate is up to 70 kilometers deep. So far, most of their findings have been highly surprising, such as the discovery of waterlogged material far below the surface, which was previously assumed to be impossible. What's more, Earth's crust itself only comprises 0.3 percent of Earth's volume, meaning that "if the planet were an apple, we wouldn't yet have broken the skin" and that nearly all of what scientists assume about Earth's interior is vague guesswork. Effectively, scientists have—both literally and metaphorically—barely scratched the surface of what there is to know about the planet humans call home.

Similarly, in biology, the discovery in 1977 of 10-foot-long worms on the Pacific Ocean's floor that survive by "chemosynthesis" (meaning they derive energy not from oxygen, but from hydrogen sulfides, which are toxic to all other known creatures) revolutionized biologists' basic assumptions about the fundamental requirements for an environment that can foster life. Bryson emphasizes that parts of the ocean (like the Mariana Trench) descend far below the depths where chemosynthesizing worms were discovered, implying that further deep ocean exploration could yield countless surprising discoveries. Oceanographers similarly suggest that "there could be as many as thirty million species of animals in the sea, most still undiscovered," while biologists estimate that overall, only 3 percent of the world's plants and animals have been discovered so far, leading Bryson to conclude that when it comes to biology, "there is a great deal we [still] don't know."

Apart from all the animal and plant species currently living on Earth, scientists also estimate that there have been five large-scale extinctions on Earth, wiping out over 95 percent of species that have lived in Earth's 4.5-billion-year existence. This means that scientists know even less about life on Earth when the broader geological scale of Earth's history is considered. Even when it comes to the human species, scientists have only just begun to understand what makes up our own biology. The human genome—comprised of 40,000 or so human genes—was only fully mapped in 2003. The human genome, however, "tells us what we are made of, but says nothing about how we work," which is now prompting scientists to map "proteomes" (a new concept capturing the genetic information that creates proteins). Bryson concludes that genetic research, too, is only in its infancy.

Bryson also argues that whenever scientists conclude that they have "pinned down most of the mysteries of the physical world," they inevitably discover that the deeper they look, the less they know, meaning the scientist's work is never—and probably will never be—done. For example, despite being advised not to pursue physics as a graduate student "because the breakthroughs [have] already been made," Max Planck revolutionized theoretical physics with his formulation of quantum theory in 1900 by showing that gravitational laws don't apply at the subatomic level. Planck's theory prompted subsequent research into the laws governing particles, which itself reveals highly counter-intuitive insights about the subatomic world and shows that humans know very little about the fundamental particles that make up our universe. For example, scientists have made the puzzling discovery that the movement of a subatomic particle in one place instantaneously triggers the movement of its "sister particle" elsewhere. This might imply that the distant universe is a reflection of sorts rather than an actual place. Subatomic particles might also be made of layers upon layers of smaller particles, implying that they could potentially contain entire universes of their own, about which nothing might ever be known. Superstring physicists now posit 11 dimensions (seven of which are, as yet, unknowable to humans), while astronomers suggest that 99 percent of the universe is comprised of invisible "dark matter," about which very little, if anything, is known at all. Such hypotheses prompt Bryson to conclude that even the most advanced theoretical scientists acknowledge that most of the universe is "beyond us," meaning there is so much more to discover. In short, Bryson argues that despite what humans think we know, there is always a new discovery lurking around the corner that might be game-changing. The universe is full of mysteries—so many, in fact, that "we really are at the beginning of it all." Scientific discovery still has a very long way to go.

WRITING, WONDER, AND INSPIRATION

In *A Short History of Nearly Everything*, author Bill Bryson argues that scientists who are plagued with poor communication skills often fail to successfully engage people with their ideas, even if those ideas have profound scientific potential. Bryson finds that the wonder of scientific discovery is often masked by dull and technical writing, rendering it inaccessible to amateurs like himself. More importantly, valuable insights can be overlooked within the professional research community if they are poorly expressed, which slows down the process of scientific discovery. Bryson essentially claims that scientists need to express their ideas in engaging ways if they want their ideas to be impactful, meaning that the scientific endeavor to understand the world hinges as much on good expression as it does on good ideas.

Bryson argues that "dull" writing undermines the potential of science to fascinate people and inspire future scientists, which can have negative effects on scientific discovery overall. Citing his own prejudices about science, Bryson says that he grew up thinking science was "supremely dull" because many textbook writers underestimate the importance of making science engaging or "comprehensible" to the reader. Bryson recalls that it was as if the author of his classroom textbook "wanted to keep all the good stuff secret by making all of it soberly unfathomable," which left him in the dark about how "any human mind" could come up with scientific ideas in the first place. For Bryson, this is a wasted opportunity because instilling "wonder" and curiosity is an essential component of inspiring children to become scientists themselves one day. Bryson offers a counter-narrative in *A Short History of Nearly Everything* by nesting scientific ideas within intriguing stories about the people who come up with them. In doing so, he shows that science isn't obtuse and inaccessible, but rather a fascinating human endeavor that anybody can pursue.

Bryson emphasizes that many obtuse phrases in textbooks—such as "anticlines, synclines, axial faults, and the like"—often originate from the insights of curious amateurs looking at the world around them. The personal diving adventures of early 20th-century deep sea divers Charles William Beebe and Otis Bartin, for example, provided early insights about "what['s] down there," and their invention of diving equipment for their hobby helped oceanography take off as a formal discipline. Similarly, the fossil hunting craze that took hold of the public's imagination in 19th-century England enabled many amateurs to discover some of the world's most important dinosaur fossils. For instance, a doctor's wife discovered the first fossilized dinosaur tooth in Sussex in 1822. Overall, Bryson aims to incite curiosity—which is what gets most scientific discovery off the ground—and dispel notions that science is only a boring matter for esoteric professionals.

Bryson similarly targets cases within the professional community in which good scientific ideas fail to catch on because they are badly written, emphasizing how important it is for scientists to communicate in ways that engage and inspire others if they want their theories to gain traction in the scientific community. For example, Bryson discusses James Hutton, who "singlehandedly and quite brilliantly […] created the science of geology" in 1785, but failed to inspire anyone to take it up—despite writing a paper and three books on the subject—because his ideas were so poorly expressed. Bryson largely blames Hutton's convoluted prose for his failure to inspire engagement in geological sciences. For example, when Hutton realized that heat within Earth creates rocks and mountain chains, his complicated wording at a conference included phrases such as: "after the body has been actuated by heat, it is by the reaction of the proper matter of the body, that the chasm which constitutes the vein is formed," which left a confused audience without "the faintest idea what he was talking about." Bryson says that Charles Lyell—the "greatest geologist of the following century," who laid the groundwork for modern geological sciences in the 1800s—admitted "he couldn't get through" Hutton's books, which implies that if Hutton's writing were more approachable, modern geological science might have included more of his ideas and would have therefore advanced much more rapidly. Bryson argues that it took almost 150 years for plate tectonics—which Hutton effectively captured in his ideas—to garner serious attention in geology, suggesting that had Hutton been able to inspire scientists with his ideas in his lifetime, over a century's worth of scientific advances might have been gained.

Bryson thus shows that "dull" writing turns off amateurs and kills—rather than instills—curiosity. It even leads professional scientists to overlook good theories when they're expressed in obtuse, convoluted prose. Ultimately, Bryson argues that bad writing and poorly-expressed ideas can dramatically limit scientific discovery, meaning that scientists should strive to write engagingly if they want their work to be impactful.

PROGRESS, SEXISM, AND DOGMA

In *A Short History of Nearly Everything*, author Bill Bryson shows how throughout history, scientists have let their prejudices stand in the way of scientific progress. Bryson argues that although certain practical obstructions to scientific progress (like the availability of technology) can't be helped, social barriers unnecessarily limiting scientific progress can—and should—be eradicated. Notably, these barriers include sexism (which undermines potential contributions by women to scientific progress) and dogmatic religious views (which make scientists resist ideas that have potential for scientific advancement). Bryson also subtly alludes to cases in which scientists undervalue scientific contributions because of their prejudices against amateurs and rival scientific disciplines. By showing how such factors have slowed down scientific advancement, Bryson argues that scientists must cultivate an atmosphere of openness by resisting counterproductive prejudices in themselves and others if they are really committed to the goal of scientific progress.

Bryson shows how sexism can inhibit scientific progress by emphasizing the profound (and often superior) contributions of women to science despite their limited access to opportunity and resources, implying that much more progress could have been made if women had had the same opportunities that male scientists of their time did. Bryson notes that sexism in early 20th-century astronomy—which restricted professional opportunities for women and denied them access to telescopes—inhibited progress in that field. He compares the insightful contributions of female clerks working in observatories to the absurd and often incorrect theories of their male counterparts. Bryson argues that a clerk (or "computer") named Henrietta Swan Leavitt's invention of "standard candles"—an "ingenious" way to measure distances between stars—is far more astute than her supervisor William H. Pickering's incorrect claim that "dark patches on the moon" are "caused by swarms of seasonally migrating insects," despite the fact that Pickering could—unlike Leavitt—"peer into a first class telescope as often as he wanted." Despite the fact that the "drudgery" of Leavitt's work surveying blurry images was "as close as women could get to real astronomy [...] in those days," Leavitt's invention changed the face of astronomy because it later enabled astronomer Edwin Hubble to prove that the universe contains many distant galaxies. Bryson thus implies that many more advances in astronomy could have been developed had dogmas like sexism not prohibited women from having better access to research tools. Similarly, Bryson emphasizes that Marie Curie (who was lucky enough to transcend late 19th-century barriers to women practicing science) was the only person in history to ever win Nobel Prizes in both Physics (1903) and Chemistry (1911). He suggests that Curie's achievement is a testament to the capabilities of people who are typically excluded from scientific pursuits, and that sexism and patriarchal values have likely held back many people who might have been able to achieve great scientific advances.

Bryson also argues that dogmas like religious conservatism slow down scientific progress when new theories are slow to be studied further because of conflicts with various religious values or because scientists fear religious persecution. A clear case of how religious dogma can interrupt scientific progress holds for Darwin's theory of evolution. Darwin formulated his theory of evolution in 1844 but locked his manuscript away for over a decade before finally publishing it in 1859 because he feared religious persecution. Darwin even alluded to his fear of persecution by referring to himself as "the Devil's chaplain." Bryson writes that it took until the late 1930s for evolutionary biology to become accepted as a scientific discipline, indicating that potential progress in evolutionary biology was set back by almost a century because of religious dogma. Similarly, Bryson explains that potential advances to mathematical sciences have also been lost to religious dogma, citing mathematician Richard Norwood. Norwood transformed sea navigation in 1637 with his research on Earth's circumference, but he burned his subsequent research in trigonometry when religious hysteria took hold in his community. He feared that "his papers on trigonometry, with their arcane symbols" might be "taken as communication with the devil and that he would be treated to a dreadful execution." A more subtle example of psychological resistance to new theories because of religious sensitivities is Einstein's uncertainty about advancing the view that light acts like both particles and waves. He was skeptical about quantum theory (which more fully develops that same view) because it posits unknowable entities. Einstein famously said that he "cannot believe for a single moment" that God would allow a universe to exist in which some things are fundamentally unknowable. Though Einstein's disdain for quantum theory did little to discredit it, he "wasted" many years of his life trying to unite quantum theory with his own relativity theory because of his discomfort with the idea that some aspects of science might be unknowable. Bryson's example thus shows how religious instincts can misdirect scientists and divert their attention away from more productive research.

Bryson frequently shows that dogmatic beliefs like sexism and religious conservatism have likely set back scientific research by decades, if not centuries. Scientific progress, thus, doesn't only depend on new theories; it also hinges on fostering openness—to ideas that question dogmatic beliefs and to people who might otherwise be denied opportunities because of patriarchal values.

EXISTENCE, AWE, AND SURVIVAL

In *A Short History of Nearly Everything*, Bill Bryson argues that life on Earth is essentially a long shot. The slightest differences in cosmic, geological, and biological events throughout Earth's history would have prevented life from being created at all. Moreover, the perpetually high odds of obliteration (from asteroids, natural disasters, and biological threats) mean that life's continued presence on Earth is an unimaginable stroke of luck. Yet, despite hanging on a perilous "knife-edge," humans often recklessly endanger life on Earth. Bryson emphasizes the fragility of our existence to instill a sense of amazement and prompt the reader to question self-destructive activities—like pollution and biological warfare—that humans willfully engage in.

Bryson argues that Earth would not have been able to sustain life had the slightest difference in early history's celestial events occurred, meaning Earth's presence as a life-sustaining planet is essentially a cosmic stroke of luck. For example, the formation of an atmosphere containing carbon dioxide at just the right time in Earth's development as a planet—when Earth was about a third of its current size and the sun was significantly younger and dimmer—created a greenhouse effect, without which "Earth might well have frozen over permanently, and life might have never gotten a toehold." In other words, Earth happened to be just the right distance from the right-sized star at just the right time in cosmic history for it to sustain life. Similarly, if Earth were a planet without a molten core, there would be no mountains and its surface would likely be smooth and evenly covered in water. Even if life was somehow able to evolve in that environment, it likely wouldn't evolve into human life (which got started when sea life evolved to crawl out of the sea). The moon was likely created by a massive asteroid impact that sent part of Earth's crust into orbit around Earth. Without the stabilizing gravitational pull of the moon, Earth would wobble on its axis, drastically affecting its climate and likelihood of sustaining life.

What's more, Bryson indicates that the likelihood of a meteor striking Earth and obliterating life—just as one did for the dinosaurs 65 million years ago—is so high that the absence of such an impact during the evolution cycle that gave rise to humans is nothing short of a miracle. Scientist Steven Osro suggests that if all the asteroids crossing Earth's orbit could be lit up and made visible to humans, we'd see "millions upon millions upon millions of nearer randomly moving objects" in space, which are all capable of "colliding with the Earth" and triggering potentially devastating effects. Bryson similarly estimates that approximately 2000 asteroids capable of obliterating life on Earth "regularly cross our orbit," meaning that the threat of destruction by asteroid impact is very real and ever-present.

Planetary fluctuations on Earth similarly threaten human life, further showing how lucky humans are to have (thus far) avoided annihilation by natural disasters. There are approximately two earthquakes each day on Earth (which scientists understand a little better since realizing Earth's crust is comprised of a series of tectonic plates floating on molten rock) but there are also "random" "intraplate quakes" capable of global devastation about which scientists know nothing so far, other than that they exist. In addition, Earth's magnetic field is variable and reversible. In the era of the dinosaurs, it was three times as strong as it is now, and it is currently diminishing. If it diminishes too much, it will no longer protect humans from cosmic radiation, which would also end life as we know it.

Bryson also argues that advances in medicine have also lulled humans into a false sense of security about the perpetual threat of disease to humanity, since we could easily be wiped out by newly evolving viruses, especially in today's globalized world in which humans' travel lifestyles "invite epidemics." Bryson argues that despite the cosmic, geological, and biological risks that all life on Earth faces on a daily basis, some of the most damaging threats to its many life forms are actually caused by humans ourselves. As far as we know, humans have been responsible for more extinctions than any other species on Earth. Between 10,000 and 20,000 years ago, human migration destroyed 75 percent of North and South America's large animals and 95 percent of Australia's. Today, scientists estimate that human-caused extinction "may be running as much as 120,000 times" higher than any damage we have caused in the past. Notwithstanding the threat to other species, ongoing mass extinction could also upset the food chain that sustains human life.

Bryson also argues that human-generated pollution increasingly threatens the delicate atmospheric balance that sustains life on Earth. For example, American engineer Thomas Midgley's 20th-century inventions of chlorofluorocarbons (CFCs)—which were mass-produced in "everything from car air conditioners to deodorant sprays"—resulted in humans unwittingly burning a hole in Earth's ozone layer, which deflects cosmic radiation that would otherwise wipe out most life on Earth. Additionally, Bryson cites several other examples of human-generated destruction, including microbial warfare (which could result in the rise of antibiotic-resistant bacteria) and atomic warfare (which could destroy all life on Earth except some insects) to show how often we wreak havoc on our already slim chances of survival.

Bryson emphasizes the delicate balance in which life on Earth hangs to show what a miracle it is that life exists at all—and that humans, in particular, exist as part of it. Bryson's aim is to foster amazement at our existence, awe for the planet we live on, and caution against the many self-destructive activities that humans carelessly engage in. So far, Bryson concludes, humans have had a lot of "lucky breaks," but it will take a lot more to keep us here in the future.

SYMBOLS

Symbols appear in **teal text** throughout the Summary and Analysis sections of this LitChart.

MATTRESS

Bill Bryson uses the metaphor of a mattress to explain the counterintuitive notion of spacetime in Einstein's relativity theory. Most people imagine that space is a vast, empty region in which our solar system (and everything else in the universe) resides. Relativity theory, however, posits that space and time are interwoven like a fabric, and that this comprises the structure of our universe. The mattress represents spacetime: if there's a heavy object on the mattress that makes it sag, then any ball that's rolled across the mattress won't roll straight across, but rather toward the sagging part. This is what we perceive as gravitational pull. Gravity, in fact, is the effect of heavy objects warping spacetime. Bryson invokes this symbol to help the reader imagine and visualize this aspect of relativity theory, as he believes that science is much more engaging when it's free of technical jargon and instead populated with visual metaphors like this one.

CATHEDRAL WITH A FLY INSIDE

When Bryson describes the structure of an atom, he uses the metaphor of a "cathedral with a fly inside" to illustrate the notion that the vast majority of an atom is empty space. The fly represents the atom's nucleus, and the cathedral walls represent the outer edges of the atom. Curiously, the nucleus is much, much heavier than the rest of the atom. To help the reader conceptualize this, Bryson says imagine the fly is heavier than an actual cathedral and that the rest of the atom weighs as much as a fly. Bryson appeals to metaphors like this to help the reader visualize and engage with scientific information that's difficult to conceptualize from abstract technical writing. In invoking the metaphor, Bryson also prompts the reader to experience amazement about the curious nature of atoms—the tiny particles that make up everything in existence.

FREEWAY

To help the reader realize just how perilous Earth's orbit actually is, Bryson leverages the metaphor of a freeway to represent Earth's orbit. Bryson describes the perpetual threat of meteors colliding with Earth and rendering life as we know it extinct, which is what happened to the dinosaurs 65 million years ago. He illustrates this idea through the symbol of Earth as the only vehicle on a freeway—a vehicle that's zooming along at breakneck speed. At the same time, there are many careless pedestrians who step into the freeway without looking for oncoming traffic. The pedestrians represent the hundreds of thousands, if not millions, of asteroids that regularly cross Earth's orbit. The metaphor thus helps the reader realize that every single day, Earth happens to dodge all these obstacles completely by chance. It also helps the reader see that although it's hard to perceive from our perspective, Earth is moving through space extremely quickly—at 66,000 miles per hour, to be exact, which explains why a collision with even a small asteroid would have such a damaging impact.

ROPE LADDER

Bryson uses the metaphor of a rope ladder to help describe the structure of DNA and the mechanism of evolution. DNA has a double-helix structure—it looks like a twisted rope ladder. The rungs on the ladder are made by the "bases" A, T, C, and G, and their order determines everything from eye color to the presence of wings. When DNA replicates, it's as if the ladder rips in half (like a zipper) and each half attaches to more bases to create two ladders. Nearly all the time, the two ladders created will be identical, meaning the rungs always stay in the same order as DNA replicates. Once in a while, however, a base will latch on in the wrong place, creating a different order of genetic code. When this happens, the body that DNA builds will be slightly different, which is how evolution occurs.

QUOTES

Note: all page numbers for the quotes below refer to the Broadway Books edition of *A Short History of Nearly Everything* published in 2004.

Introduction Quotes

To be here now, alive in the twenty-first century and smart enough to know it, you also had to be the beneficiary of an extraordinary string of biological good fortune.

Related Characters: Bill Bryson (speaker)

Related Themes:

Page Number: 2-3

Explanation and Analysis

Bryson begins his book by exclaiming that the reader—like every other human being on Earth—is lucky to be here. Bryson means that human existence lies at the end of an unfathomably long chain of events tracing all the way back to the dawn of life on Earth as microbes, just under four billion years ago. Although this seems like a long time from our perspective, it's actually surprisingly short for such a feat of evolution. The evolution itself depends on a near infinite chain of events that had to happen in precisely the way they did at exactly the time they did—the slightest alteration might have resulted in a completely different arrangement of affairs, including an absence of humans.

In this quote, Bryson also reflects that not only did this "extraordinary string" have to happen just how and when it did, it also had to happen alongside a lot of other events—including meteor collisions and volcanic activity—happening when they did as well as not happening when they didn't. Bryson's intent is to emphasize how lucky humans are to exist at all and how easily things could have gone awry but didn't, meaning that we are even more lucky with all of that considered. Life, for Bryson, is both extraordinary and precious: it could have very easily not happened at all. Bryson's intent is to prompt a sense of awe and amazement in his readers at the very fact of their existence, so that they appreciate it instead of taking it for granted.

Bryson also aims to dispel the idea that humans were somehow *supposed* to exist, or that our existence was inevitable. He thus questions religious beliefs centering on creationism—the idea that life is created with a purpose by a divine creator—which Bryson thinks hinder the scientific endeavor by over-privileging the human experience.

❝ I didn't doubt the correctness of the information for an instant—I still tend to trust the pronouncements of scientists in the way I trust those of surgeons, plumbers, and other possessors of arcane and privileged information—but I couldn't for the life of me conceive how any human mind could work out what spaces thousands of miles below us, that no eye had ever seen and no X-ray could penetrate, could look like and be made of.

Related Characters: Bill Bryson (speaker)

Related Themes:

Page Number: 4

Explanation and Analysis

Bryson introduces *A Short History of Nearly Everything* by discussing why he became interested in writing this book. Here, he recalls that he doesn't actually know much about scientific discovery—he knows, of course, that scientists know important things about the world, but he has no way of connecting with the process of discovery as well. For Bryson, this is symptomatic of a tendency in science writing to focus on facts, formulas, and technical claims. What Bryson plans to do in this book is something different: he wants to connect the theories that give rise to technical details with the human endeavor of discovery. For Bryson, behind every claim is an inquiring, curious, fascinated mind—and the only way the endeavor will continue is through the efforts of other similarly inquisitive people.

Thus, Bryson's focus in the book is on the human stories behind scientific theories. This way, the reader can connect more fully with the sense of mystery and wonder that scientists experience, the obstacles they face, and curiosity that motivates them. His hope is to bring science to life in this way so the reader realizes that everybody can engage in the task of scientific discovery and become similarly motivated to do so. After all, for Bryson, there's a lot of work to do when it comes to science, and the more people involved, the better.

❝ And here's the thing. It wasn't exciting at all. It wasn't actually altogether comprehensible.

Related Characters: Bill Bryson (speaker)

Related Themes:

Page Number: 5

Explanation and Analysis

Bryson is discussing his motivations for writing *A Short History of Nearly Everything* in his introductory chapter. Here, he relates an anecdote about a science textbook that he was excited to read in elementary school before realizing that it was full of inaccessible technical terms and thoroughly boring. Bryson thinks that overly-abstract and technical writing obscures everything that's interesting about science—which is, at its core, a human endeavor based on fascination and curiosity about the world around us. For Bryson this sort of writing doesn't only fail the reader by rendering scientific knowledge inaccessible—it also fails science itself. Without curious young children who are fascinated by science, there won't be passionate, dedicated, scientific researchers to keep the task of scientific discovery moving forward.

Bryson also compares the images in the textbook—which he finds profoundly stimulating—with the text, which he finds profoundly dull. He clues the reader in here to one of his central mechanisms in fostering excitement about science in his own writing: Bryson often appeals to metaphors that help the reader visualize the phenomena they're learning about. He thinks that verbally illustrating concepts in this way makes the phenomena themselves more engaging and more memorable, which prompts both curiosity and better learning.

Chapter 2 Quotes

❝❝ We have been spoiled by artists' renderings into imagining a clarity of resolution that doesn't exist in actual astronomy. Pluto in Christy's photograph is faint and fuzz—a piece of cosmic lint—and its moon is not the romantically backlit, crispy delineated companion orb you would get in a National Geographic painting, but rather just a tiny and extremely indistinct hint of additional fuzziness.

Related Characters: Bill Bryson (speaker), James Christy

Related Themes:

Page Number: 20

Explanation and Analysis

Bill Bryson is introducing the science of astronomy, which he centers here on the discovery of Pluto's moon. Bryson discusses this case because it seems odd that scientists can detect so many things with precision, but don't realize Pluto has a moon until 1978, when James Christy discovers it. Here, Bryson reminds the reader that scientific discovery is often limited by the availability of technology. This isn't something that can be helped—it's just a fact that scientific discovery hinges on the ability to detect what's out there, which depends on the sophistication of the technology that can detect it.

Bryson's point implies two important things: first, that the task of scientific discovery will likely never be complete. The more advanced technology is developed, the more scientists can refine earlier claims and explore things that they couldn't detect before. This implies that there is always the possibility of more scientific work to do as the tools for doing that work continue to improve. Second, there are already vast limitations on what scientists *can* do with the technology that they have, so they shouldn't further limit themselves with preventable obstacles to scientific progress, like prejudices (notably against women) and dogmas (such as religious biases).

❝❝ When I was a boy, the solar system was thought to contain thirty moons. The total now is "at least ninety," about a third of which have been found in just the last ten years. The point to remember, of course, is that when considering the universe at large, we don't actually know what's in our own solar system.

Related Characters: Bill Bryson (speaker)

Related Themes:

Page Number: 25

Explanation and Analysis

Shortly after discussing the size of the solar system, Bryson emphasizes that scientific knowledge about its contents keeps evolving. This makes sense, given how vast the solar system is, and the fact that humans haven't traveled beyond than the moon. A lot of scientific discovery also depends upon technology, which is also evolving. Even with advanced technology, humans are often prone to error—mistaking, for example, a smudge on a telescope image for one object when actually there are two there. All these factors lead Bryson to conclude that scientific discovery is an ongoing pursuit. In fact, it will likely be an ongoing pursuit for as long as humans exist, partly because science evolves as exploration and technology evolves and partly because humans often have to revise erroneous prior claims.

Bryson's frequent claims about how little we know—evidenced here with regard to our barely knowing what's *in* the solar system, let alone anything more *about* these things—implies that scientists are largely at the beginning of their journey and that the vast majority of scientific work lies ahead.

Chapter 5 Quotes

❝❝ Nearly every line he penned was an invitation to slumber.

Related Characters: Bill Bryson (speaker), James Hutton

Related Themes:

Page Number: 63

Explanation and Analysis

Bryson is discussing the birth of geology as a science in the 1700s, which begins with James Hutton. Hutton formulates many profound insights about Earth—such as the fact that mountains are created by moving land masses that collide—as early as 1795, but they largely fail to gain scientific traction, only resurfacing as viable scientific explanations in the late 20th century. Here, Bryson explains that Hutton's ideas fail to take on because he's an incredibly obtuse writer who bores everybody attempting to read his work. Bryson argues that Hutton phrases his ideas in such indecipherable prose that nobody can understand what he's talking about.

Hutton's poor writing is thus directly responsible for people's failure to understand and adopt his ideas, which significantly hinders progress in geology. It takes almost 200 years of erroneous theorizing about the formation of mountains for geology to get back on track. Bryson implies that all this wasted time and effort could have been avoided had Hutton tried to express himself in a clearer and more engaging way, meaning that scientific progress is fundamentally dependent upon clear, engaging, and accessible scientific prose.

Chapter 7 Quotes

Perhaps nothing better typifies the strange and often accidental nature of chemical science in its early days than a discovery made by a German named Henning Brand in 1675. Brand became convinced that gold could somehow be distilled from human urine [...] None of it yielded gold, of course, but a strange and interesting thing did happen. After a time, the substance began to glow. Moreover, when exposed to air, it often spontaneously burst into flame.

Related Characters: Bill Bryson (speaker), Henning Brand

Related Themes:

Page Number: 97

Explanation and Analysis

At the beginning of Bryson's discussion of scientific progress in chemistry, he raises the case of Henning Brand, who—on the basis of a hunch—tries to distill urine into gold but ends up accidentally discovering phosphorus (which enables the invention of matches).

Bryson discusses Brand to show that scientific discovery often gets off the ground on the basis of hunches, and many discoveries happen accidentally. These two factors in the process of scientific discovery imply that scientific discovery can come from anyone—all it takes to get going is a curious person with an idea. It's also never clear what the outcome of experimentation will be, since unexpected and surprising things can (and often do) happen. This implies that the endeavor of scientific discovery will likely continue as long as people keep conducting experiments, because there's always a chance of another accidental discovery and a new insight waiting around the corner, no matter how much scientists believe they already know.

Marie Curie would win a second prize, in chemistry, in 1911, the only person to win in both chemistry and physics.

Related Characters: Bill Bryson (speaker), Marie Curie

Related Themes:

Page Number: 109

Explanation and Analysis

Bryson is discussing early 20th century advances in physics and chemistry. He raises the case of Marie Curie, who's the only person in history to win Nobel Prizes in both Physics (for her work in radioactivity) and Chemistry (for her discovery of new elements including polonium). Bryson makes Curie's contribution to scientific progress explicit here because it's a tremendous achievement. Moreover, it's achieved by a woman.

Despite Curie's success as a scientist, patriarchal values at the time severely inhibit women's abilities to pursue scientific careers. The obstacles faced by women in science continue well into the mid-20th century, and arguably, even into the present day (albeit more subtly). Bryson brings up Curie's achievement to show that sexist biases which privilege the scientific capabilities of men are completely unfounded. In fact, Curie achieves a feat that no man was ever able to achieve. Bryson thus shows that the less patriarchal bias there is among professional scientists—or, the more openness there is to historically marginalized people—the more scientific progress will be possible. To Bryson, it's clear, time and time again, that the people who are marginalized by prejudice are often some of the most prolific contributors to scientific progress.

Chapter 8 Quotes

Just to put these insights into perspective, it is perhaps worth noting that at the time Leavitt [was] inferring fundamental properties of the cosmos from dim smudges on photographic plates, the Harvard astronomer William H. Pickering, who could of course peer into a first class telescope as often as he wanted, was developing *his* seminal theory that dark patches on the Moon were caused by swarms of seasonally migrating insects.

Related Characters: Bill Bryson (speaker), Edwin Hubble , Henrietta Swan Leavitt

Related Themes:

Page Number: 130

Explanation and Analysis

Bryson is discussing Hubble's discovery that there isn't just one, but potentially billions of galaxies in the universe—meaning that it's far vaster than anyone ever imagined. Bryson emphasizes that Hubble's theory is dependent on Leavitt's invention of "standard candles," an "ingenious" way to measure distances between galaxies in the universe.

Bryson stresses that the professional atmosphere in early 20th-century astronomy is hostile to women. Most women—like Leavitt—are relegated to working as "computers," people who survey photographic images. Despite Leavitt's limited resources, she is able to advance science tremendously by looking only at "dim smudges on photographic plates." Bryson juxtaposes Leavitt's profound contribution to science with Pickering's absurd and incorrect theory in order to show that sexist beliefs in the superiority of male scientists, as well as the privileging of resources for male scientists, are completely unfounded.

In juxtaposing Leavitt with Pickering, Bryson implies that the women "computers" are substantively more competent than the male astronomer. For Bryson, this means that patriarchal values that limit opportunities for women in science severely hold back scientific progress. Bryson implicitly prompts the reader to imagine what leaps could have been made if women were not relegated to support staff and were permitted direct access to telescopes. All of this implies that scientists should strive to free their research environments from prejudices—like sexism—that deny or limit access to people who are not typically associated with scientific discovery.

Chapter 9 Quotes

The "shell" of an atom isn't some hard shiny casing, as illustrations sometimes encourage us to suppose, but simply the outermost of these fuzzy electron clouds. The cloud itself is essentially just a zone of statistical probability beyond which the electron only very seldom strays. […] It seemed as if there was no end of strangeness.

Related Characters: Bill Bryson (speaker), Werner Heisenberg , Niels Bohr

Related Themes:

Page Number: 145

Explanation and Analysis

Bryson is discussing early 20th century advances in particle physics that focus on what, exactly, an atom is. In 1913, Niels Bohr discovers that electrons (one of the three known components of atoms, along with protons and neutrons) don't move like other particles. In fact, they jump in space around the atom's nucleus (which is densely packed with protons and neutrons). Bohr names this phenomenon "quantum leap." Then, Werner Heisenberg realizes that it's possible to know where an electron is, or the path it takes as it moves, but not both—he names this the "uncertainty principle." In this quote, Bryson tries to visualize the atom on the basis of these findings, which imply that an atom is more like a nucleus plus a field of "probability" in which the electron will most likely pop up as it jumps around in space.

As Bryson notes, the concept of an atom is full of "strangeness," and things only get stranger as particle physicists discover more about the tiny particles that make up the fabric of existence. Bryson emphasizes the "strangeness" of this area of science to show that the universe is full of mystery. This finding shows that no matter how much of a handle scientists think they have on a phenomenon, they often find that the closer they look, the more surprising and mysterious things become. This implies that scientific discovery not only leads to scientific knowledge, but also further scientific mysteries to unpack. Bryson thus believes that the task of scientific discovery will likely continue for a very long time—and it may, in fact, never be complete—since each scientific discovery unfolds further mysteries to be unraveled.

Einstein couldn't bear the notion that God could create a universe in which some things were forever unknowable.

Related Characters: Bill Bryson (speaker), Max Planck , Albert Einstein

Related Themes:

Page Number: 146

Explanation and Analysis

Bryson has just been discussing Einstein's discovery of relativity theory and Max Planck's simultaneous discovery of quantum theory. The presence of both theories as bodies of scientific knowledge shows that the rules of gravity and relativity—which Einstein believes hold for the universe at large—don't apply at the subatomic level. Particles, according to quantum theory, are governed by a completely different set of rules and might themselves be comprised of infinitely smaller particles that humans will never get to the bottom of.

Einstein is appalled by the idea that there are aspects of the world—such as the behavior of subatomic particles that humans can't detect—that will always be opaque to scientists. Bryson explains that Einstein's views are motivated by his religious intuition that God wouldn't design a world in which "some things were forever unknowable." Einstein's religious intuition leads him to invest the majority of his life unsuccessfully trying to bring the two theories—relativity theory and quantum theory—together. Bryson raises this example to show how religious intuitions can muddy the scientific endeavor and misdirect the efforts of scientific minds down paths that are unfruitful.

Bryson thus believes that religious intuitions tend to slow down the scientific endeavor because they make scientists waste valuable research time trying to tally their scientific reasoning with their religious beliefs. For Bryson, it makes much more sense for scientists to free their inquiries from the need to defend religious hunches, since this wastes valuable research time and therefore hinders scientific progress. Bryson advocates that scientists strive to foster an openness to new ideas—even, and especially, when they conflict with religious beliefs.

Chapter 10 Quotes

Seldom has an industrial product been more swiftly or unfortunately embraced. CFCs went into production in the early 1930s and found a thousand applications in everything from car air conditioners to deodorant sprays before it was noticed, half a century later, that they were devouring the ozone in the stratosphere. As you will be aware, this is not a good thing.

Related Characters: Bill Bryson (speaker), Robert Midgley Jr.

Related Themes:

Page Number: 151

Explanation and Analysis

Just after discussing Midgley's discovery that the addition of lead to gasoline reduces engine shudder but pollutes the environment with atmospheric lead, Bryson discusses Midgley's invention of chlorofluorocarbons (CFCs). Here, Bryson explains that CFCs have disastrous effects on Earth's atmosphere because they destroy ozone. Ozone is essential for human survival because it prevents radiation from space from penetrating the atmosphere and killing all the life in its path. Bryson thus shows, with this example, how humans are often quick to adopt materials they know little about with disastrous effects on our chances of survival as a species.

Bryson argues that humans often act recklessly with our environment, throwing the delicate balance of things that are necessary for our survival in disarray. This is problematic for Bryson because life is rare and precious, and it's already precarious because of near-infinite risks to life from things outside human control, such as meteors. Essentially, Bryson believes that humans are already in such a perilous position that we should take care to avoid reckless activities like industrial activity that needlessly destroys our environment, because such behavior only renders our own annihilation more likely and more swift.

Chapter 11 Quotes

Carl Sagan in *Cosmos* raised the possibility that if you traveled downward into an electron, you might find that it contained a universe of its own, recalling all those science fiction stories of the fifties.

Related Characters: Bill Bryson (speaker), Carl Sagan

Related Themes:

Page Number: 164

Explanation and Analysis

Bryson is discussing particle physics and the discovery of subatomic particles and their components. Reflecting on the nature of these phenomena, Bryson invokes Carl Sagan to suggest that even the tiniest particles we can fathom might themselves contain infintely smaller universes of their own that are fundamentally unknowable to humans. Here, Bryson indicates the common phenomenon of scientists realizing that the harder they look at something, the more mysterious it becomes. Each new insight exposes just how little scientists know, which suggests that there are some things scientists might never know. Bryson implies that the scientific endeavor will likely never be complete because every time scientists discover something new, they also discover a host of new questions and mysteries to be solved. The harder scientists look, it seems, the more they realize how little they actually know and how much more scientific work lies ahead. Thus, Bryson thinks that scientific discovery will probably continue for as long as humans exist.

Chapter 13 Quotes

❝❝ Think of Earth's orbit as a kind of freeway on which we are the only vehicle, but which is regularly crossed by pedestrians who don't know enough to look before stepping off the curb. At least 90 percent of these pedestrians are quite unknown to us. […] All we know is that at some point, at uncertain levels, they trundle across the road down which we are cruising at sixty-six thousand miles per hour. […] The number of these relative tiddlers in Earth crossing orbits is almost certainly in the hundreds of thousands and possibly in the millions, and they are nearly impossible to track.

Related Characters: Bill Bryson (speaker), David Levy , Eugene Shoemaker

Related Themes:

Related Symbols:

Page Number: 193-194

Explanation and Analysis

Bryson is discussing efforts by Shoemaker and Levy to catalog asteroids in the asteroid belt. The two scientists realize that craters on Earth are caused by meteors crashing into Earth, and they suspect that one of these might be responsible for the extinction of the dinosaurs. Bryson addresses the risks of asteroid impacts today, and he is astounded to learn that they are incredibly high. In fact, life on Earth is perpetually at high risk of obliteration, without warning, at every moment of the day.

To help the reader visualize this, Bryson uses the metaphor of Earth as a vehicle on a highway (Earth's orbit) that's being forever crossed by unwitting passengers (meteors). Bryson uses the metaphor to emphasize that although it doesn't feel like it from our perspective, Earth is barreling through space at an enormous speed directly in the path of millions of other objects and narrowly missing catastrophic collisions in every passing moment. Bryson often uses metaphors to help readers visualize a phenomenon because he thinks they are more effective than dry, technical, abstract details.

Bryson's aim is to show how precarious our existence is, since it could be wiped out without a moment's notice. All of this means humans are very lucky that such an event hasn't happened yet. Our existence amid such hostile conditions is, for Bryson, largely a matter of sheer luck.

Chapter 15 Quotes

❝❝ Yellowstone, it appears, is due.

Related Characters: Bill Bryson (speaker)

Related Themes:

Page Number: 228

Explanation and Analysis

Shortly after discussing the ever-present threat of catastrophic asteroid impacts, Bryson discusses threats to life within Earth's own ecosystem, beginning with volcanoes. Bryson raises the example of Yellowstone to show that it's a particularly dangerous "supervolcano"—a caldera that, when it next erupts, will spew out so much molten rock that the eruption will destroy most of the Americas and have profound effects on Earth's climate for thousands of years. Bryson emphasizes all this to show how precarious life on Earth is. The threat of asteroid impacts notwithstanding, cataclysmic natural disasters can also wipe out life as we know it, meaning that our existence is perpetually at risk.

Bryson continues to explain how scientists have recently discovered that Yellowstone's magma chamber erupts every 600,000 years. The last eruption was just over 600,00 years ago, which prompts Bryson to say that Yellowstone is "due." This means that catastrophe isn't merely possible, it's inevitable. It may not happen in the reader's lifetimes, but it will happen soon. Bryson emphasizes this because he wants the reader to realize how precious life is, how lucky humans are to still be here, and how much awe we should feel regarding our planet.

Chapter 16 Quotes

❝❞ The real terror of the deep, however is the bends—not so much because they are unpleasant, though of course they are, as because they are so much more likely.

Related Characters: Bill Bryson (speaker)

Related Themes:

Page Number: 241

Explanation and Analysis

Bryson is describing the activities of deep-sea divers who brave the depths of the ocean and end up relaying scientific knowledge about deep ocean life to the rest of us on the surface. Bryson emphasizes that deep-sea divers put themselves at enormous risks, since the pressures at such depths are life threatening, triggering a phenomenon called "the bends," in which nitrogen bubbles from our lungs migrate into the bloodstream and start to fizz, triggering violent agony and sometimes death.

Bryson makes a point of describing this phenomenon to emphasize that most of Earth's environments are off-limits to humans. We can barely penetrate the ocean depths, let alone survive down there—nor can we survive in high altitudes, frigid Antarctic temperatures, or deserts. In essence, humans are "ground hugging" beings that are dependent on Earth's land masses to survive. Bryson stresses all this because he wants the reader to realize how precarious human existence is, and how limited it is to a specific environment, so that the reader becomes critical of damaging human activity (like air pollution that could trigger climate change and rising sea levels) that endangers the already tiny sliver of Earth that we can survive on.

The limitations that humans face in traversing many of Earth's environments also mean that scientific knowledge about places like Earth's oceans is woefully limited—we barely know much about them at all because it's so hard to get down there, meaning that scientists have a long way to go before they can claim to know all there is to know about Earth.

Chapter 18 Quotes

❝❞ It was a world independent of sunlight, oxygen, or anything else normally associated with life. This was a living system based not on photosynthesis, but chemosynthesis, an arrangement that biologists would have dismissed as preposterous had anyone been imaginative enough to suggest it.

Related Characters: Bill Bryson (speaker)

Related Themes:

Page Number: 279

Explanation and Analysis

Bryson is discussing scientific exploration of Earth's oceans. He explains how one expedition near the Galapagos showed that there are entire living ecosystems deep in the ocean which derive their energy from hydrogen sulfides, which are toxic to air-breathing creatures and most other life forms.

Bryson emphasizes how surprising this discovery is to show that most often, when scientists start to look around, they are increasingly perplexed by the phenomena they discover. Here, they learn that entire ecosystems thrive in conditions previously thought to be inhospitable to life. This indicates how limited scientific knowledge of the world is and how there are likely countless other mysterious things to learn about the oceans as we begin to explore them more fully. Bryson thus argues that the scientific endeavor is truly young and has a long way to go.

Bryson also stresses how amazing it is that life can exist in such conditions—deep in the ocean without sunlight or oxygen. This is a testament to life's diversity and its near-miraculous tendency to crop up in the unlikeliest of places. Life, for Bryson, is so amazing that it truly deserves our awe and our respect.

❝❞ In fact, by 1957-58 the dumping of radioactive wastes had already been going on, with a certain appalling vigor, for over a decade.

Related Characters: Bill Bryson (speaker)

Related Themes:

Page Number: 280

Explanation and Analysis

Byson is in the midst of discussing scientific endeavors in oceanography when he raises the issue of dumping radioactive waste in the oceans during the 20th century. Many nations have been dumping—and continue to dump—toxic materials into Earth's oceans since the early 20th century. This is astounding to Bryson because humans have little to no idea about the impact this will have on ocean life. What's more, our survival as a species is dependent upon ocean activity, including many organisms who absorb carbon from water and prevent it from populating the atmosphere with levels of carbon that would render human life unsustainable. Bryson calls out this sort of reckless behavior to show that human existence hangs in the delicate balance of a complex ecosystem that we intentionally and carelessly abuse, meaning that our activities could well trigger our own extinction. In addition, our lack of knowledge about the effects of our activities on our ecosystem also shows how little we know about Earth and how much scientific work there is yet to do, implying that science is only at the beginning of its journey.

Chapter 20 Quotes

Remarkably, by one estimate, some 70 percent of the antibiotics used in the developed world are given to farm animals, often routinely in stock feed, simply to promote growth or as a precaution against infection. Such applications give bacteria every opportunity to evolve a resistance to them.

Related Characters: Bill Bryson (speaker)

Related Themes:

Page Number: 315

Explanation and Analysis

Bryson is discussing the role of bacteria in life on Earth. Having explained that some bacteria are essential to our survival while others can kill us, he wonders why humans use antibiotics so profusely in our commercial endeavors. Here, he explains that many farm animals are carelessly pumped full of antibiotics for purposes of industry. This alarms Bryson because bacteria—like every other living thing on Earth—are continually evolving. The presence of antibiotics in their environment enables bacteria to evolve a resistance to them, meaning that soon enough, antibiotics will be useless at fending off disease from newly evolving bacteria. Humans are effectively endangering our own survival since we could easily be annihilated by an incurable pandemic of disease-causing antibiotic-resistant bacteria, an outcome that we make increasingly likely with our excessive use of antibiotics. Bryson raises this point to argue that humans should not gamble so recklessly with our own existence—survival as a species is tough enough without careless behavior that renders our extinction ever more likely.

Chapter 25 Quotes

Darwin kept his theory to himself because he well knew the storm it would cause. In 1844, the year he locked his notes away, a book called Vestiges of the Natural History of Creation roused much of the thinking world to fury by suggesting that humans might have evolved from lesser primates without the assistance of a divine creator.

Related Characters: Bill Bryson (speaker), Charles Darwin

Related Themes:

Page Number: 386

Explanation and Analysis

Bryson is discussing how Darwin developed his theory of evolution after a five-year around-the-world voyage on the HMS *Beagle*. Darwin formulates his theory in 1844 but keeps it a secret, locking his notes away for almost 15 years. In this passage, Bryson explains why: Darwin is tormented by the thought that his theory will cause a "storm" among the "thinking world" because of the amount of hostility against theories (like Robert Chambers's claim that humans evolved from primates) that eliminate the role of a "divine creator" and thus conflict with religious beliefs. Because Darwin locks his notes away for so long, and because his theory is met with such resistance, research in evolution doesn't take off until the 1930s, almost a century later. Bryson thus shows that both religious prejudice and the fear of religious persecution are directly responsible for setting science back by almost a century. Bryson implies that scientists should strive to free themselves of religious prejudice and cultivate an atmosphere of tolerance to new ideas, otherwise the scientific endeavor will advance far more slowly than it's capable of progressing.

And these, you may recall, are men who thought science was nearly at an end.

Related Characters: Bill Bryson (speaker), Gregor Mendel, Charles Darwin

Related Themes:

Page Number: 396

Explanation and Analysis

Bryson has just been discussing Darwin's theory of evolution and Mendel's discoveries about the mechanism of heredity. Together, they lay the foundation for modern biology, which kicks off around 1930. Curiously enough—as this quote shows—many scientists are eager to declare the scientific endeavor complete before modern biology has even gotten off the ground. Bryson raises this point to emphasize that inflated claims about scientific achievements couldn't be further from the truth. Science, for Bryson, is such a recent pursuit that's its far from complete. In fact, it's only in its infancy because there is so much that scientists don't yet know.

Bryson's quote is also deeply ironic, since the "men" who are so eager to congratulate themselves on their knowledge are often incorrect, and they frequently hold back others (like women) from participating in the scientific endeavor despite how much work there is to be done. Thus these "men" haven't helped the scientific cause so much as hindered it with their prejudices, which cause them to limit the speed of scientific progress and generate premature, overinflated claims about their own achievements.

Chapter 26 Quotes

If Franklin was not warmly forthcoming with her findings, she cannot altogether be blamed. Female academics at King's in the 1950s were treated with a formalized disdain that dazzles modern sensibilities (actually any sensibilities). However senior or accomplished, they were not allowed into the college's senior common room but instead had to take their meals in a more utilitarian chamber that even Watson conceded was "dingily pokey." On top of this she was being constantly pressed—at times actively harassed—to share her results with a trio of men whose desperation to get a peek at them was seldom matched by more engaging qualities, like respect.

Related Characters: Bill Bryson (speaker), Maurice Wilkins, James Watson, Francis Crick, Rosalind Franklin

Related Themes:

Page Number: 405

Explanation and Analysis

While discussing the race among scientists at King's College London in the 1950s to discover DNA's double-helix structure, Bryson paints an ugly picture of the research environment that women scientists have to tolerate in this time period. Franklin, the only woman among four scientists studying DNA, is frequently treated with disrespect, which prompts her to be secretive about her own findings.

Bryson raises the example of Franklin to show how patriarchal biases and outright sexism create hostile research environments because women—who are often treated with disdain—are often undermined by their male colleagues, making them less likely to want to collaborate. Collaboration, Bryson implies, drives research forward, and any environment that fosters hostility among scientists limits collaboration. Sexism is thus directly responsible for holding back scientific progress, since it undermines the contributions of women, dissuades them from collaborating with men, and creates unpleasant work environments that dissuades women (with tremendous potential for scientific discovery) from joining the pursuit of scientific knowledge.

Perhaps an apogee (or nadir) of this faith in biodeterminism was a study published in the journal Science in 1980 contending that women are genetically inferior at mathematics. In fact, we now know, almost nothing about you is so accommodatingly simple.

Related Characters: Bill Bryson (speaker)

Related Themes:

Page Number: 412

Explanation and Analysis

Bryson is discussing advances in genetic research, which is a very recent scientific endeavor. He explains that scientists who are eager to understand heredity start pursing research about specific inherited traits. Here, Bryson mentions a paper that defends "biodeterminism," the idea that all our human capabilities are inherited by specific genes. The paper is problematic because it falsely argues that women are "genetically inferior at mathematics." Bryson often alludes to the barriers to entry for women in science, arguing that sexist biases significantly impede scientific progress for much of science's history. Here, he exposes another way in which sexism impedes the scientific endeavor: it prompts researchers to try and reconcile science with their biases. Patriarchal prejudice can thus prompt scientists to jump to conclusions, make erroneous claims, and lead other scientists in the wrong direction when it comes to scientific discovery. All this takes precious research time that becomes wasted because it's misdirected, and Bryson thus argues that sexism directly holds back scientific progress.

Chapter 27 Quotes

❝❞ The extraordinary fact is that we don't know which is more likely, a future offering us eons of perishing frigidity or one giving us equal expanses of steamy heat. Only one thing is certain: we live on a knife-edge.

Related Characters: Bill Bryson (speaker), Wladimir Köppen , Milutin Milankovitch, James Croll

Related Themes:

Page Number: 432

Explanation and Analysis

Bryson is discussing ice ages and the scientists—including Croll, Milankovitch, and Köppen—who strive to figure out what causes them. In exploring this material, Bryson unfurls another mystery that is indicative of how limited human knowledge about the world is.

Scientists have good evidence to believe that climate change could either trigger a catastrophic ice age or catastrophic heat, but they have no idea which outcome is more likely. Increased carbon dioxide in the atmosphere could affect Earth's climate so that cloud cover triggers cooler summers, leaving more ice on Earth's surface to deflect the sun's heat and trigger a global deep freeze. On the other hand, increased carbon dioxide in the atmosphere could create a greenhouse effect that melts the ice caps, triggering dramatic rises in sea level and temperatures that render human life unsustainable. The fact that scientists don't know which outcome is more likely shows how limited our knowledge of Earth is and how much more work scientists have to do to get an adequate grasp on the mechanisms of this planet we call home.

At the same time, the fact that both outcomes are catastrophic for human life shows that in either case the prognosis isn't good, which is curious considering how much human activity knowingly contributes to rising carbon dioxide levels. Bryson thinks that our existence is already perilous enough, and we live on a perpetual "knife-edge," so the last thing humans should be doing is acting so recklessly that we ourselves make life on Earth unsustainable.

Chapter 30 Quotes

❝❞ We really are at the beginning of it all. The trick, of course, is to make sure we never find the end. And that, almost certainly, will require a good deal more than lucky breaks.

Related Characters: Bill Bryson (speaker)

Related Themes:

Page Number: 478

Explanation and Analysis

Bryson's closing sentence—captured here—at the end of *A Short History of Nearly Everything* summarizes his thesis about the continued survival of the human species. Bryson explains that humans haven't been around for very long at all, only 100,000 years of Earth's 4.5-billion-year history, meaning we are only at the dawn of what's possible for our species. The fact that we exist at all and have continued to survive thus far is matter of sheer chance and blinding good fortune. Yet despite this, we continually act in ways that endanger both our survival, and the survival of all life on Earth, with activities like recreational hunting, pollution, industry, and warfare. This, for Bryson, is cataclysmically foolish, since our existence already hangs in the balance of a perilous and volatile Earth, and hostile cosmos. If we want to continue surviving, thus, we should recognize how amazing it is that we're here at all and treat the planet with respect and care, rather than engaging in self-destructive activities.

SUMMARY AND ANALYSIS

The color-coded icons under each analysis entry make it easy to track where the themes occur most prominently throughout the work. Each icon corresponds to one of the themes explained in the Themes section of this LitChart.

INTRODUCTION

Bill Bryson begins by saying he's glad the reader could make it. Truth be told, it's a "miracle" that humans are here at all, considering that we're made of "mindless" atoms that coalesce into people (and everything else in the universe) for a time before dispersing (for unknown reasons).

Bryson begins by emphasizing that the reader's existence is nothing short of astonishing. He clues the reader in to a central idea in the book: that the happenstance of human existence is extremely lucky and worthy of profound appreciation.

As a child, Bryson finds science books terribly boring and technical. One day, however, he's on a long flight over the Pacific Ocean, and he realizes how little he knows about why Earth works the way it does. He starts thinking about how scientists work things out. Why do they know some things (like how the universe started) and not others (like if it will rain next Wednesday)? Moreover, is it possible to marvel at scientific achievement at a level that is neither too technical nor too simplistic?

Bryson raises another central idea in the book—that scientific knowledge ought to instill readers with a sense of wonder about the world, but that this is often stymied by bad writing that hinders the impact a scientific discovery. Bryson aims to articulate scientific ideas in a more intuitive, accessible way so that readers realize science isn't esoteric and dull, but a worthy and exciting pursuit.

CHAPTER 1: HOW TO BUILD A UNIVERSE

Protons, which are unimaginably tiny particles, are one of the foundational building blocks of the universe—about 500,000,000,000 of them could fit in the dot of an "i" printed on a page. In the infancy of a universe, a proton shrinks down to one billionth of its normal size into a space so tiny that the particle looks "enormous" by comparison. This is then packed into about an ounce of matter. Essentially, in the creation of a universe like ours, every particle that exists is compacted into an unfathomably compact space like this. Then, a blinding pulse that causes rapid expansion (or a "Big Bang") sets the universe into motion—but rather than spreading out to fill empty space, the only space that exists is what the universe creates as it expands. Scientists disagree about when this happened for our universe, though most estimate that it happened about 13.7 billion years ago.

Bryson gives a clue to the vast scope he will cover in the book, ranging from unimaginably tiny particles to the vastness of an entire universe. Part of Bryson's aim is to show that there is so much ground to cover that it's practically impossible to know everything about the universe humans live in. Bryson emphasizes that a lot of science is based on speculation—say, about when the universe started—to show that scientists still have many questions to uncover.

The idea of the Big Bang wasn't popularized until the 20th century. Two radio astronomers named Arno Penzias and Robert Wilson are setting up a large Bell Labs communications antenna in New Jersey in 1965, but they can't get rid of this weird background hiss no matter what they try. Unbeknownst to them, a team of scientists led by Robert Dicke at Princeton University are looking for that exact hiss—cosmic background radiation left over from the Big Bang. After connecting with Dicke, Penzias and Wilson realize what they have found, and they write a paper about their discovery. Dicke also writes a paper about what it means. In the end, Penzias and Wilson (but not Dicke) win the 1978 Nobel Prize in Physics.

Bryson explains that many scientific ideas are fairly new—like the idea of the Big Bang. Bryson also emphasizes that situations leading to scientific discoveries are often accidental, meaning there is an active component of luck and timing in the nature of scientific discovery. In addition, scientific recognition doesn't always align with scientific achievement, and prejudices among scientists (say, in favoring the discovery of a phenomenon over the explanation of it) often interfere with giving credit where credit is due.

The Big Bang was more like a rapid expansion than an explosion. Robert Guth comes up with this idea, which is known as "inflation theory" after he is inspired by one of Dicke's lectures at Princeton University. A fraction of a second after the Big Bang, gravity emerges, then other nuclear forces, followed by elementary particles (photos, protons, neutrons, and electrons). What's more extraordinary is how well it turned out for us: if one component had been slightly different, we wouldn't be here.

Bryson emphasizes that human existence is contingent on history working out exactly the way it did—the likelihood of everything coming together to form a universe that's compatible for human life is very, very low, but somehow this did happen. Bryson's aim is to instill a sense of awe about how lucky we are to be here.

That's why some experts think our Big Bang might be one of many such events that occurred many times over. There might have been billions of them beforehand, and there might be many more after. Or, there might be lots of simultaneous universes, each with slightly different features. In that case, finding a universe that can sustain human life (from among many slightly different universes) is more like going into a department store and finding a suit that fits among many others that don't, as astronomer Martin Rees put it.

Bryson offers another explanation for our existence in which our universe is one of many. Bryson shows that scientists often debate about the correct interpretation of the phenomena they are analyzing and that scientific knowledge is by no means complete. There are many things about which scientists speculate, including how many universes there might be.

Bryson asks where he'd be if he tried to cross past the edge of the galaxy. Oddly enough, the answer is: back at his starting point. This is because space curves in a way that's hard to understand. It's a bit like thinking the world is flat, circling Earth, and not understanding why one is right back where one started. Bryson also wonders how the universe went from mostly light gases (like hydrogen, helium, and lithium) to compounds like oxygen and carbon, and, more importantly, where "here" is.

Bryson introduces a puzzling question to show that science is intriguing but full of counterintuitive conclusions, and it often seems inaccessible. However, with the right description—say, about Earth being round instead of flat—many things that seem bizarre at first make a lot of sense. This means that science is more accessible than many people might initially assume, even for something as complicated as spacetime theory.

CHAPTER 2: WELCOME TO THE SOLAR SYSTEM

Astronomers can detect all sorts of cosmic events and objects—they can even detect distant radiation that's so faint it has less energy than a snowflake does when it hits the ground. It's funny, then, that nobody realized Pluto has a moon until James Christy discovered it in 1978. This is partly because professional telescopes don't scan the sky (they're set up to look at fixed parts of the universe and are costly to reposition) and also because both Pluto and Pluto's moon like fuzzy specs of lint through a telescope. Before then, astronomers thought that the moon and the planet were one speck instead of two.

Bryson emphasizes that scientific discovery has come a long way. Humans have acquired the capacity to comprehend some of the finest details about our universe (such as minute variations in distant radiations). Nonetheless, there are many things we don't know much about at all, such as Pluto's moon. Often, limitations in our knowledge happen because of the limits of technology, meaning it takes both good data and a bright mind to piece together a scientific claim.

Astronomer Percival Lowell first postulates Pluto's existence (though he also thinks Mars's canals were built by ancient Martians and that Pluto was a gas giant). A young amateur named Clyde Tombaugh finally finds Pluto—it's a strange planet because nobody knows what it's made of, and its orbit isn't on the same plane as the other planets in our solar system (it's like a tilted hat). Technically, there are many Pluto-like objects in that part of space—some no larger than a lump of coal. Scientists have discovered over 600 of these objects since 2002, when curiosity about objects in that region—which is four billion miles away—increased.

Bryson wants to dispel the idea that humans know a lot about the universe by showing that even the closest cosmic objects continue to evade us: we haven't yet figured out the objects in our own solar system, let alone the universe at large. Bryson also emphasizes our lack of knowledge about the universe by showing how many false hypotheses—say, Lowell's postulation about Martians—that scientists conjure up. Finally, Bryson shows that often, the scientific pursuit is helped by curious amateurs like Tombaugh. This means that the more curious people there are, the more scientific discoveries are made, which is why it's so important for science writing to be engaging and accessible—it fuels human curiosity that leads to scientific knowledge.

It's hard to imagine how far away four billion miles is. Light can get there in seven hours, but it took the Voyager spacecrafts over a decade (and only because Jupiter, Saturn, Uranus and Neptune lined up in the right way, which happens every 175 years). If Bryson were to map the distance and he made Earth the size of a pea, Jupiter would be a thousand feet away, while Pluto would be 1.5 miles away and would be the size of a "bacterium." From Pluto, the sun looks like a pinhead, just a bright star among others in the sky.

Bryson emphasizes the vast scale of the universe by helping the reader imagine a scale model of the solar system. Realizing how far away Earth is from other planets and objects drive home just shrouded in mystery our universe is and how much ground scientists need to cover. The scientific endeavor, thus, has a long way to go. Bryson's scale model also helps emphasize how lucky it is that one planet in this enormous solar system sustains life, since in all this vastness we haven't discovered any planets besides Earth that are hospitable to life.

Astronomers also keep discovering new objects, meaning we still don't know what's in our own solar system, which stretches to the Oort comet cloud that's 10,000 miles beyond Pluto on Bryson's scaled map. The Oort cloud is a peaceful cluster of comets marking the outer edge of the solar system. Sometimes, a comet gets nudged out of orbit and flies inward toward a potential collision with the planets, or it flies outward into the desolation of space. It would take 25,000 years for an Oort cloud comet that's nudged out of orbit to reach the next star.

Once again, Bryson emphasizes how vast space is to instill a sense of awe in the reader and to prompt a feeling of appreciation that in all this vastness, there happens to be one tiny spot where life can thrive: Earth. With this in mind, Bryson aim to convey how lucky humans are to be here.

The average distance between stars is 20 million million miles. It's hard to imagine aliens coming from so far away just to make crop circles on Earth, but it's not improbable that they exist. Scientists think that there are 100-400 billion stars in the Milky Way and 140 billion other galaxies. A scientist named Frank Drake calculates that there are likely millions of other advanced civilizations in the cosmos. However, the nearest one would be over 200 light years away, meaning if they were looking at Earth right now, they'd see the French Revolution and people in powdered wigs.

Bryson expands the incomprehensibly large scale of the universe: the sheer magnitude of space makes it difficult to pin down much scientific knowledge at all. This is especially true when not only distance, but time, is warped by space's vastness. Just as faraway aliens wouldn't see us as we are now, being light years away from other objects means we aren't able to see more than an image of the past when we seek to learn about space.

CHAPTER 3: THE REVEREND EVANS'S UNIVERSE

On clear nights, amateur stargazer Reverend Robert Evans looks at dying stars from his back-porch telescope in Australia as a hobby. What Evans sees, however, is the stars as they were when their light left them, before traveling many light years toward Earth. The North Star we see now is the North Star as it was 680 years ago—it might have died since then, for all we know.

Bryson picks up on the idea of Earth's immense distance from other celestial bodies, which he raised at the end of the last chapter, in order to emphasize that human knowledge of space is often limited to things that happened a long time ago because that's all we can see. The fact that the night sky might look radically different in real time shows how little we know about the universe's present state.

When a massive star dies, it releases a blip of light as bright as 100 billion suns: those blips are what Evans hunts. He's so good at it that it's like covering a Walmart parking lot with dining room tables and shaking a pinch of salt on each one. If you added one extra grain to one of those tables, Evans would be able to spot the difference. He doesn't have any special training, just a good eye and a knack for memorizing star fields.

Bryson emphasizes how skilled Evans is by comparing his stargazing to spotting a grain of salt added to an entire parking lot's worth of space. Scientific knowledge, then, depends not only on specialized training but the presence of individuals with the right intuitive skills, like a good eye and good memory.

In 1930, an aggressive fitness buff, bully, and "irritating buffoon" named Fritz Zwicky coins the term "supernova." He hypothesizes that if a star were to collapse into a dense, concentrated core, atoms would be crushed together and their electrons and protons would create neutrons, leaving enough energy leftover to make a big light explosion that would be visible across the universe. Despite Zwicky's "revolutionary" ideas, he has no how to prove his hypothesis. Zwicky also predicts that there's extra mass in the universe that humans can't see, which we now call "dark matter." Five years later, Zwicky's colleague Oppenheimer popularizes the idea of neutron stars "in a landmark paper" but doesn't cite Zwicky because of Zwicky's bad attitude.

Bryson's story about Zwicky and Oppenheimer shows that scientific discovery arises from a blend of big thinking (to come up with a good idea or hypothesis) and specialized training (to provide evidence and data for the idea or hypothesis). Bryson also emphasizes the limited scale of human knowledge about the universe—there are some things, like dark matter, which we can't even see or detect. Finally, Bryson alludes to internal politics among scientists, which he will expand on as he begins to weave in the impact of prejudices on the scientific endeavor.

Supernovae are extremely rare—spotting one is like standing on top of the Empire State Building and spotting someone lighting a 21st birthday cake in the window of a Manhattan building, which makes Evans's skill even more formidable. His excellent memory of star fields helps, as does his location (the Southern Hemisphere), and his telescope (which he can move around easily, unlike massive professional telescopes). Most nights, however, Evans finds nothing.

Bryson invokes another metaphor—of spotting a candle being lit from the Empire State Building—to emphasize the vast scale that astronomers are working with, and the sheer imperceptibility of the data they're looking for. All this shows that there are many mysteries to be uncovered, and a lot of perseverance is often necessary to uncover them.

Nowadays, it's easy to automate the process with a digital camera attached to a telescope that scans the sky, but Evans thinks that kills the "romance" of it all. Bryson wonders what would happen if a nearby star exploded. He asks astronomer John Thorsten, who tells Bryson that if a supernova were to happen near Earth, it would evaporate the magnetosphere (the magnetic zone around Earth that protects humans from harmful radiation) and annihilate us instantly. Luckily, there aren't any stars large enough to collapse into supernovae close enough to Earth for that to happen.

Bryson introduces the idea of how easy it would be to obliterate human existence in order to help the reader realize how lucky we are to still be here and how precarious our existence is. He'll expand substantially on this idea throughout the book. Here, for example, it's just a matter of chance that there aren't potential supernovae close enough to Earth to destroy us.

Supernovae are important because they explain where the energy came from that was needed to transform the universe's basic gases to elemental matter after the Big Bang. In 1957, scientist Fred Hoyle shows how heavier elements are formed through supernova explosions, though his colleague W. A. Fowler receives a Nobel Prize for the discovery. Hoyle also shows that the energy released from a supernova enables interstellar material called "gaseous clouds" (with all the matter needed for life) to form and cluster. Controversially, Hoyle also believes that pathogens rain down on humans from space and that the Natural History Museum's fossils are hoaxes, causing national outcry in the United Kingdom. Nonetheless, Hoyle's research on supernovae helps scientists to piece together an origin story for "how we got here," which Bryson summarizes next.

Bryson shows that it takes until 1957 for scientists to understand an important clue to the origins of life, which shows how young the scientific endeavor is and how far it has to go. Hoyle's controversial claims about pathogens and fossils, however, show that scientists sometimes make absurd and bizarre claims that are often wrongly taken seriously because they are men who are in a position of power in the scientific world. Bryson thus begins to introduce the notion that patriarchal values can misdirect scientific progress.

About 4.6 billion years ago, a 15-billion-mile-wide gas cloud gathered where we are in space, and 99.99 percent of it created the sun. Two miniscule dust grains floated close enough to each other to connect via electrostatic forces, marking the conception of Earth. Grains kept colliding until a few clumps were big enough to dominate their orbits, gather more clumps, and form planets. 4.5 billion years ago, a Mars-sized object crashed into Earth, causing some of Earth's crust to separate and form the Moon. The moon began orbiting Earth, and its gravitational pull stabilized Earth on its axis.

Bryson's origin story for the formation of Earth emphasizes how much chance is involved in Earth winding up as a planet that could sustain life. Earth's conception—from dust clinging to dust—is a matter of pure chance. Furthermore, the chance collision with an asteroid creates a moon that can stabilize Earth on its axis, rendering the climate stable and the conditions for life possible. All of this is a sheer matter of chance.

When Earth was about a third of its current size, an atmosphere of gases including carbon dioxide formed. The sun was much younger and dimmer then, but the carbon dioxide in Earth's atmosphere created a "greenhouse effect" that concentrated the sun's rays, warming Earth. If it wasn't for that early greenhouse effect, Earth would have frozen over and life wouldn't have got going at all. After 500 million years of further collisions from asteroids and passing debris, life somehow got going. Four billion years later, Earth exists as we know it today.

Once again, Bryson emphasizes how much chance was involved in Earth forming an atmosphere that's hospitable to life. Without the early greenhouse effect when the sun was dimmer, Earth would be a frozen empty desolate planet. Further chance collisions with asteroids all contribute to our existence, showing how rare it is that life began on Earth at all.

CHAPTER 4: THE MEASURE OF THINGS

In 1735, a group of French scientists led by Pierre Bouguer and Charles Marie de la Condamine attempt to trek through the Andes Mountains to work out Earth's circumference by measuring a 200-mile stretch of land near the Equator. The trip is a disaster: the locals pelt the scientists with stones, their doctor is stabbed and killed in a lover's quarrel, several scientists die of illness, and one runs off with a teenager, never to return. They also have to wait eight months in Lima, Peru for permits, because authorities don't believe their reasoning for why they need to go all the way to the Andes to do their calculations.

Bryson's story about Bouguer and Condamine emphasizes how science can be rendered engaging as a human endeavor of discovery, intrigue, and adventure (rather than a dull and lifeless set of theories in a textbook). He also shows that scientific discovery in the 18th century is fraught with obstacles, highlighting another barrier to scientific knowledge that limits the speed of scientific discovery.

The answer to the question of why these scientists need to go to the Equator goes back to Edmond Halley, a sea captain, scientist, and mathematician who makes many inventions and scientific contributions in his lifetime (the famed Halley's Comet is named after him). After making a dinner bet in 1638, Halley becomes obsessed with finding out why Earth's orbit is elliptical, and he seeks out Isaac Newton's advice. Newton tells Halley that he's actually already figured out why the orbit is elliptical—but he forgot where he wrote down the explanation. Bryson says that this is like finding a cure for cancer and forgetting where you noted it down. On Halley's pressing, Newton sits down to recalculate the formula and ends up writing and publishing a book called *Principia*, which changes the face of science forever.

Once again, Bryson works up to Newton's discovery of gravity and the laws of motion with engaging personal details about Halley and Newton, emphasizing the human context around Newton's work. Bryson also uses humor to render stories about scientific discovery more engaging, for example, when describing Newton's eccentric behavior. For Bryson, these sorts of descriptions help readers to absorb and retain scientific information and to become genuinely curious about the nature of Newton's claims.

Newton's book identifies the laws of motion and it contains the discovery of gravity. The laws of motion are: (1) an object moves in same the direction toward which it's pushed, (2) an object will move in a straight line if undisturbed by other forces, (3) every action has an equal and opposite reaction, and (4) every object in the universe pulls others toward it. This fourth law means that every object has a gravitational pull that's proportional to its mass and the inverse of the squared distance from the object it pulls. This means that if the distance between two objects is doubled, the gravitational pull between them becomes four times weaker. Controversially, *Principia* also claims that Earth is a slightly squashed sphere—slightly flatter at the poles but wider at the Equator.

Having peaked the reader's curiosity, Bryson now explains the central tenets of Newton's laws of motion. Bryson thinks that nesting scientific theories and laws (like these one) in human contexts helps the reader to retain the information being absorbed. Bryson is also careful to use simple language and clear example, so that the writing is clear and easy to absorb, which is another quality he believes is important to scientific writing.

If Newton is right, it means that prior calculations about Earth's circumference and mass are wrong, because, up until this point, scientists assumed that Earth was a perfect sphere. Robert Norwood makes one such calculation a few years earlier by walking 208 miles from the Tower of London to York measuring the distance on the ground with a chain. Norwood wants to know the width (or circumference) on Earth's surface that one degree of a circle captures, if that degree were to originate from Earth's center and extend out toward the surface (like a slice of pie). Norwood calculates this distance as 110.72 kilometers, while French astronomer also Jean Picard uses a different geometric method to estimate slightly more accurately that it's 110.46 kilometers.

Bryson's next move is to apply Newton's laws to a tangible problem (such as Earth's shape) to show how abstract theories engage with real-world inquiry. Thus, Bryson emphasizes the connection—rather than the distance—between science and human curiosity. Norwood's quest to estimate the circumference of a degree arc is similarly imbedded in memorable details like his use of a chain. Norwood's effort also emphasizes the challenges to scientific knowledge faced by early scientists given a lack of technology, which implies that there's always more scientific work to be done as measuring tools improve.

In 1669, however, father and son team Giovanni and Jacques Cassini dispute Newton's claim that Earth is slightly flattened (like a tangerine) and argue that it's actually slightly elongated (like an egg). To settle the dispute, two expeditions are sent off from France: one (led by Bouguer and Condamine) to measure the circumference of a degree at the Equator and another to Scandinavia to measure the circumference of a degree near the North Pole. If the circumference of a degree at the Equator is longer than elsewhere, Newton's hypothesis is correct. Nine-and-a-half grueling years later, Bouguer and Condamine discover that Newton was indeed right. Even worse for them, the French team trekking in Scandinavia worked it out and beat them to the punch.

Bryson completes the tale of the expedition, thus bookending Newton's theory in a tangible human story, once again using humor and irony to render ideas (here, about Earth's shape and circumference) more memorable. The grueling nature of such expeditions emphasizes that early scientific discovery is fraught with obstacles. Bryson thus implies that one of the reasons why scientific knowledge is still in its infancy is because it simply takes a lot of effort to learn things about the world in this stage of history.

Newton also argues in *Principia* that a plumb bomb hung near a mountain will tilt toward the mountain, which Nevile Maskelyne and Charles Mason attempt to prove in the 1770s. Ten years earlier, however, they have a different challenge: to measure the passage of Venus across the sun (known as a "transit") so that they can calculate Venus's distance from the sun. Halley had wanted to do that himself, but Venus didn't transit in his lifetime. Venus's peculiar orbit means that the planet passes across the sun (or "transits"), then passes again eight years later, but then it disappears for 125 years.

Bryson stresses that our knowledge of many things—particularly cosmic events—is limited because of the narrow chances of witnessing cosmic events in the flesh. These kinds of natural limitations show that scientific discovery is at the mercy of cosmic timing, and that there are likely many cosmic events humans have yet to witness, and that we've therefore yet to acquire scientific knowledge about.

One of the first international collaborative scientific efforts was a series of expeditions across the world to measure the transit of Venus from multiple places. The expeditions, however, are ill-fated. Jeanne Chappe's journey to Siberia is halted by a flooded river just before he reaches his destination, and Guillame Le Gentil travels a year to India only to have a cloud block the transit from view at just the wrong moment. Another ship, carrying Charles Mason and Jeremiah Dixon (who famously plot the Mason-Dixon line in the American wilderness a few years later) is attacked by the French before they reach their destination in Sumatra.

Bryson's story about the ill-fated effort to measure the transit of Venus shows once again how scientific discovery is often stymied by everyday obstacles like bad weather. His inclusion of this story again shows how much effort and how many people are involved in making scientific claims, emphasizing how chance circumstances can impede the speed of scientific discovery. It also once again situates a scientific claim in an intriguing story of human adventure, thus fostering curiosity and engagement in the reader.

Eventually, Maskeleyne's team—who compare the various measurements of Venus's transit—conclude the 1761 effort failed due to too many conflicting measurements. Eight years later, in 1769, British explorer James Cook completes the task from Tahiti, before claiming Australia as a British colony. Using Cook's measurements of Venus's transit, a French astronomer named Joseph Lalande calculates that Earth is 150 million kilometers from the sun.

Maskeleyne's analysis shows that scientific claims often involve the interpretation of conflicting, partial, or inadequate data, leaving a lot of room for error. Bryson thus stresses how scientists can think they've figured something out before learning that their knowledge is incorrect and requires further inquiry.

Once that issue is resolved, Maskeleyne turns back to the issue of plumb bombs tilting toward mountains. In 1774, he makes a lengthy survey—full of complicated measurements—of Scotland's Schiehallion mountain to test Newton's hypothesis. Maskeleyne's measurements prove essential to the ongoing quest to figure out Earth's mass: Charles Hutton ends up using them to estimate Earth's mass (at 5,000 million million tons) and to deduce the mass of the sun and other planets. Incidentally, he also invents contour lines (which connect points of equal height on a mountain) when he makes a diagram of Maskeleyne's measurements.

Bryson implies that scientific experiments often have a broader potential for knowledge than is initially apparent. Here, Maskeleyne's effort to test Newton's hypothesis about gravity ends up helping Hutton to make progress in another scientific quest (about Earth's mass). This is one of the reasons why Bryson thinks scientific claims should be articulated in accessible ways: they might have hidden potential that would remain inaccessible if the findings are not expressed well enough for others to use.

Twenty-three years later, a pathologically shy Henry Cavendish (who is terrified of people looking at him or speaking to him in public and only communicates with his household servants through notes) figures out a more accurate measurement of Earth's mass. He estimates it to be six billion trillion metric tons (each metric ton weighs 1000 kilograms), which he deduces using a curious machine invented by a country parson named John Michell, who leaves it to Cavendish in his will.

John Michell is an amateur who isn't professionally trained in science, but he invents a machine with profound scientific potential out of sheer personal curiosity. Through this example, Bryson further underscores the need for science to engage everyone (not just esoteric scientists), because breakthroughs can come from anyone if they are curious and engaged enough to think about scientific problems.

Incidentally, Cavendish also discovers at least five scientific laws later coined by other scientists, as well as electrical conductivity and a way to discover the noble gases. However, Cavendish is too shy to publish his findings in his lifetime. Despite vast advances in technology, no scientist has since improved upon Cavendish's 1797 measurements. Bryson says that by the late 1700s, we thus knew Earth's precise dimensions and accurate distances between the planets and the sun.

Bryson reemphasizes the import of Michell's contribution to science as an engaged amateur, since his machine enables the most accurate measurement of Earth's mass to date. Bryson also shows that it takes the better part of a century to figure out the solar system and Earth's dimensions, indicating that scientific mysteries take a long time to solve. The multigenerational nature of scientific discovery shows that there is always more scientific work to be done and more progress to be made.

CHAPTER 5: THE STONE BREAKERS

Bryson describes Scottish scientist and farmer James Hutton (born in 1726) as the inventer of geology but a painfully obtuse writer. In Hutton's time, many scientists are wondering why so many clam fossils are found on mountaintops. "Neptunists" believe that changes in sea levels are responsible (meaning the mountains were once underwater), while "Plutonists" think volcanic eruptions spewed clams out from the sea and landed them on top of mountains. While examining soil on his farmland, however, Hutton has a brilliant insight: he realizes that if the mountains were once underwater, erosion would have made them smooth, like pebbles.

So far, Bryson has stressed that scientific claims need to be accessible for their full impact to be realized. Here, he provides a tangible example of a case in which brilliant ideas are impinged by bad writing. Bryson begins by describing Hutton's idea—that mountains can't have been underwater because they betray no signs of erosion—in simple, intuitive language, which he will shortly contrast with Hutton's own convoluted prose.

Mountains aren't smooth, however—they're clearly made of jagged surfaces that would have eroded away if they were once underwater. Hutton concludes this must mean that the mountains rose up out of the ground, taking even older clam fossils with them when the mountains formed. He also deduces that heat within Earth must be responsible for warping its surface to make mountains. Hutton's intuitions are correct—they anticipate plate tectonics theory, which argues that mountains are created when tectonic plates that slide around on hot molten rocks smash into one another.

Bryson continues explaining Hutton's insights in clear, digestible prose to emphasize the importance of this kind of scientific description. Hutton effectively anticipates plate tectonics theory almost two centuries before it's fully accepted in the scientific community, but, as Bryson is about to show, Hutton's own poor writing is partially responsible for why his ideas are overlooked.

Hutton publishes several books on his findings, but unfortunately they're written in such convoluted prose that nobody understands what he's talking about. His insights are thus completely ignored by the scientific community. Charles Lyell, who later lays the foundations of modern geology, admits that "he couldn't get through" Hutton's books. Hutton's insights are marginally salvaged when Hutton's good friend, mathematician John Playfair (who "could write silken prose") summarizes Hutton's ideas in 1802, five years after Hutton's death.

Bryson emphasizes that clear, engaging writing is essential for scientific progress by comparing Hutton's poor writing with Playfair's "silken prose." Had Hutton written like Playfair, his ideas might have been incorporated into the geological scientific community much more easily. Hutton's inaccessible writing is thus directly responsible for Lyell's failure to emphasize their import when he lays the foundations of modern geology.

Geology takes the 19th-century world by storm. Roderich Murchison's 1839 book *The Silarium System* (about rocks) is a bestseller, and Lyell's 1841 lectures on marine zeolites are sold out in Boston. People venture to the country for a bit of leisurely "stone breaking"—in formal attire, no less—including Lyell's eccentric professor, the Reverend William Buckland (who famously tried to eat one of every animal that existed).

Bryson shows that even the most seemingly dull scientific pursuits (like Lyell's lectures on "marine zeolites") can foster tremendous public engagement when they are well-expressed. This is important because public engagement (in activities like "stone breaking") can tangibly contribute to scientific progress.

In this period, geologists are divided into two camps about the events that shaped Earth in its early history. Buckland is a "catastrophist" who believes catastrophic events like floods shaped Earth. This also aligns with Buckland's faith, since Christianity references ancient floods and plagues and such. His student Lyell, on the other hand, is a "uniformitarian": he believes that change happened slowly and gradually. Eventually, the uniformitarian view wins out, and Lyell goes on to become the father of modern geological thought, publishing the landmark *The Principles of Geology* in 1830. His work is profoundly influential—Darwin even takes a copy with him when theorizing evolution in the Galapagos.

Bryson introduces the idea that religious beliefs can misdirect scientific perspectives with the case of Buckland, whose emphasis on the scientific importance of catastrophic events is inspired by his Christian faith. This example begins to weave in the idea that religious dogma often impinges scientific progress. In this case, Buckland's ideas lose their momentum, but Bryson will soon raise many other examples in which religious beliefs end up costing scientists valuable time and efforts in the quest for progress.

In this era, scientists agree on four broad geological eras—Precambian, Palezoic, Mesozoic, and Cenozoic—but they still don't know what time periods apply for each age. Speculation abounds about Earth's age, coming from every corner of Europe's intellectual community. Irish Archbishop James Ussher concludes that Earth was created at "midday on October 23, 4004 B.C.," to scientific ridicule. Even the eccentric Buckland thinks biblical genesis lasted "millions upon millions of years."

Bryson uses humor to ridicule Ussher's claim about Earth's creation and further expose how unfounded religious ideas can—if they're taken seriously—sway scientists in the opposite direction of progress. The lack of knowledge about the duration of Earth's geological eras shows that a lot of scientific knowledge about Earth's history is yet to be uncovered.

Compte de Buffon, meanwhile, runs strange experiments that involve heating up model globes until they're white-hot and then touching them to measure heat loss. He estimates that Earth is approximately 75,000-168,000 years old, while Darwin curiously claims that parts of Earth are 306,662,400 years old before rescinding his suggestion. Even the illustrious Lord Kelvin—who patents modern refrigeration, devises absolute temperature, and makes profound contributions in thermodynamics—is stumped. He assumes that the sun is young because it still has "fuel," and he grossly underestimates Earth's age despite fossil evidence to the contrary.

Bryson runs through several figures who try, in all sorts of eccentric ways, to estimate Earth's age. His examples show how much speculation and guesswork is involved in scientific claims, meaning that there is always a wide margin for error. Bryson's example of Lord Kelvin shows that scientific mysteries can elude even the brightest minds, meaning that even when fiercely intelligent people dwell on a problem, the answer can still be evasive and demand further inquiry.

CHAPTER 6: SCIENCE RED IN TOOTH AND CLAW

In 1787, the first dinosaur bone ever discovered is found in a New Jersey creek, though it goes unrecognized and ends up lost in a store room. Around the same time, the influential Compte de Buffon makes damning comments about the "New World," claiming it's a toxic wasteland full of tiny, shriveled animals and disfigured natives. His views are much to the chagrin of Thomas Jefferson, who starts a trend of sending expeditions out to find bones, sending them to Europe to disprove Compte de Buffon's claims.

Bryson uses humor (with the story of the dinosaur bone that ends up lost in a store room) to emphasize that humans really know very little about Earth's history, so much so that we can easily overlook important artifacts. Buffon's damning criticisms about the "New World" expose the interrelatedness of prejudice and scientific progress. Sometimes, as is the case here, the desire to dispel prejudice can fuel scientific discovery—though most of the time, the opposite happens.

From these expeditions, woolly mammoth bones start cropping up all over the United States and are sent to Europe alongside theatrical overestimations of the mammoth's capabilities, including speculation that it pounces like a tiger and has fangs. (It turns out that someone piecing together pieces of a mammoth skull screwed on tusks upside down, and they were mistaken for fangs). When the famous bone examiner George Cuvier receives some mammoth bones in France, he names the creature a "mastodon" (meaning "nipple teeth") and develops the theory of extinction. Jefferson is unable to believe that God would allow for such a cruel fate as extinction to happen, so he commissions an expedition westward to seek out living mastodons and disprove Cuvier's claim.

Bryson emphasizes how easy it is to make grave scientific errors with the humorous example of tusks that are mistaken for fangs. He implies that the scientific endeavor is fraught with error, meaning there is always room for improvement—no matter how much humans think we know. Bryson also provides another case in which religious intuitions misdirect scientific efforts with Jefferson. Jefferson spends funds (that could be used in more productive ways) on a misguided hunt for living mammoths on the basis of his belief in a benevolent creator.

Meanwhile in England, mining surveyor William Smith deduces in 1796 that the ages of various fossils ages line up with different layers (or "strata") of rock. He maps Britain's rock strata in 1815 and prompts a fossil hunting craze, although dinosaurs aren't recognized as such until 1855. Some of the most influential (though often overlooked) fossil hunters of this time include 12-year-old Mary Anning, who carefully excavates and sells "sea monster" fossils in Dorset from 1812 (most are now housed in London's Natural History Museum). She inspires the tongue-twister "she sells sea shells on the sea shore." A fossilized dinosaur tooth is also discovered in 1822 by Mrs. Mantell, the wife of a country doctor named Gideon Algernon Mantell.

Bryson leverages Smith to show how something that seems boring on the surface—like rocks—can capture the public imagination if well-expressed and can therefore have a profoundly more impactful effect on scientific progress through the engagement of amateurs. Bryson subtly alludes to the exclusion of competent women from the scientific endeavor in this era. Mary Anning's skill in excavating fossils is unparalleled and profoundly important (evidenced by the presence of her fossils in London's Natural History Museum), though her contributions aren't recognized in her own lifetime because she is neither a scientist nor a man.

The eccentric Buckland publishes a paper on the fossilized tooth that Mrs. Mantell found, but because he doesn't know about dinosaurs yet he assumes it comes from an ancient lizard, which he names "iguanadon." The term "dinosauria"—meaning "terrible lizard"—isn't coined until 1841 by a "sinister" anatomist named Richard Owen. Owen steals the country doctor Mantell's discoveries of countless dinosaur fossils after Mantell is crippled in a riding accident. Owen renames many samples to hide his thievery, and Mantell is driven to suicide in 1852, after which Owen (allegedly) writes a damning obituary accusing Mantell of plagiarism.

Bryson's macabre story of the rivalry between Owen and Mantell shows that scientific engagement can run so deep that it ends up becoming a matter of scandal, theft, and even life or death situations. The potential for engagement in scientific progress is thus very high if scientists express themselves in ways that capture the public imagination. Buckland's assumption that Mantell's fossilized tooth belongs to a lizard exposes, once again, limitations in scientific knowledge.

Eventually, Owen is caught claiming credit for another amateur naturalist's discovery and is subsequently pushed out of the Royal Zoological Society. Uncharacteristically, Owen later revolutionizes museum culture by devising the new Natural History Museum as a place accessible by all classes instead of only the permit-bearing elite. However, Owen he also leads a smear campaign against Charles Darwin and has Darwin's statue in the museum relegated to the back of the coffee shop.

Owen's uncharacteristically generous efforts to make museums more accessible to the public shows that scientific progress is often held back by social prejudice. Here, Bryson shows that prejudiced views limit amateurs' access to museums until well into the 19th century, which is counterproductive considering how many contributions amateurs make to science.

Meanwhile, a ruthless competition between wealthy Americans Edward Drinker Cope (who notoriously hunted for bones amid the battle of Little Big Horn) and Othniel Charles March (whose uncle built a museum for him) changes the face of paleontology. Cope and March increase the number of dinosaur species discovered from 9 to 150—including many popular species like brontosaurus and triceratops—through an all-out rivalry that includes sabotaging each other's digs and stealing each other's samples.

Bryson once again shows how a piece of information that would likely be found in a science textbook (specifically, the number of dinosaur species we know about) can be rendered more compelling. By framing this information within the dramatic anecdote of Cope and March's feud, Bryson is able to more effectively engage the reader than he would by simply stating an abstract fact.

By the start of the 20th century, several tons worth of new dinosaur bones have been excavated, leaving the next generation of scientists perplexed about how to age them and reconcile them with wild speculations about Earth's age (which range from 5,000 years to millions of years), though none of the estimates come anywhere near the ballpark of the actual time of the dinosaurs, which was 65 million years ago. Eventually, a New Zealand farm boy named Ernest Rutherford provides "irrefutable evidence" proving that Earth is at least several hundred million years old.

Bryson's survey of where scientific knowledge about Earth's history stands by the start of the 20th century shows how much scientific advancement is a never-ending process. Specifically, the question of Earth's age is still in play at this point, and significant fossil analysis needs to be completed at this stage in history. Bryson thus implies that the more scientists discover, the more they learn how limited their knowledge (thus far) is.

CHAPTER 7: ELEMENTAL MATTERS

Chemistry evolved almost accidentally out of alchemy in the 1600s, mentioning a German named Henning Brand who attempts to distill gold out of human urine in 1675. Brand fails, but he does accidentally create phosphorous after noticing that a batch of urine glows and spontaneously bursts into flames. Ironically, phosphorous is deemed so commercially potent that its retail price surpasses the price of gold after Swedish chemist Karl Scheele devises a way to mass produce it in the 1750s (catapulting Sweden into becoming the world's largest producer of matches). Scheele insists on tasting every substance he works with, and he's eventually found dead at his workbench surrounded by toxic substances in 1786.

Bryson stresses that many scientific contributions come from curious amateurs (like Brand), underscoring why it's important for science to be engaging: it can stimulate curiosity and trigger experimentation, as Brand's efforts show. Bryson's memorable story of Brand's urine bursting into flames also illustrates how scientific claims can be articulated through engaging stories, thus making scientific history come to life and prompting the reader's engagement.

Chemistry is "thrust into the modern age" by Antoine-Laurent Lavoisier, who amasses wealth from France's poor with his despised tax collection company Fermé Générale. Though Lavoisier never discovers an element, he devises the system for naming elements (along with his wife, Madame Lavoisier). During the French Revolution, Lavoisier is denounced by his failed rival Jean-Paul Marat, and he meets his fate at the guillotine in 1793. Almost a hundred years later, a prestigious statue of Lavoisier is discovered to have been built using the wrong severed head as its model, and it's melted for scrap metal during World War II.

Bryson shows how the scientific contributions of women are often obscured by patriarchy, since Antoine-Laurent Lavoisier is often solely credited for scientific work that he completed in collaboration with his wife. As before, Bryson emphasizes the human context around scientific discovery—another rivalry, it seems, ends up being a matter of life or death—thus illustrating how scientific history can be brought to life with memorable anecdotes.

Bryson argues that chemistry "lost its bearings" in the early 1800s, noting that nitrous oxide becomes popularized as the recreational "drug of choice" among England's fashionable youth decades before its potential as an anesthetic is realized. The field of chemistry also suffers because of limitations in technology, and it also has a lower status because it's seen as a commercial—rather than academic—enterprise. Eventually, an American named Benjamin Thompson (later Count von Rumford) sets up the British Institute after narrowly escaping being tar-and-feathered in the American Revolution and inventing the drip coffee maker. Humphry Davy, the institution's professor of chemistry, develops electrolysis and discovers many new elements— including aluminum, potassium, sodium, calcium, and magnesium—before dying from his nitrous oxide habit.

Bryson compares two factors that limit scientific progress: one that can't be helped (namely, limitations in technology) and one that can (specifically, dogmatic belief in the superiority of academic enterprises). At this time, scientists are snobbish about contributions that are commercial in focus, and their prejudice slows down progress in chemistry. By contrasting these two factors, Bryson shows that science is already hindered by many things that can't be helped—like limitations in technology—so it's especially important for scientists to free themselves of prejudices that can impede scientific progress.

Chemistry isn't formally established until the mid-1800s after J. J. Berzelius standardizes element symbols, and Dmitri Ivanovich Mendeleyev devises the periodic table of elements in 1869. Incidentally, Mendeleyev only studied chemistry because his destitute mother hitchhiked 4,000 miles across Russia and convinced a scientific school to take him in when he was young.

Here, Bryson stresses that the importance of good expression in science isn't limited to words—it also applies to symbols, tables, and other graphic elements that aid scientific discovery. Bryson also credits scientific progress to the often-unacknowledged perseverance of women (such as Mendeleyev's mother).

Mendeleyev—inspired by the card game solitaire—organizes elements according to atomic number (number of protons per atom): hydrogen (one proton) comes first, while uranium (92 protons) comes last. Mendeleyev astutely assumes that the 63 elements discovered in his time aren't the full picture, and so he devises the periodic table with placeholder spots that accurately predict where many new elements will slot in, allowing for further additions to be easily integrated. The periodic table is widely considered history's most elegant chart, accommodating today's 92 natural elements and a further 28 synthetic ones created thus far.

Bryson leverages the periodic table to show how scientific information, when well-expressed, can foster scientific progress. Bryson shows how the logic of Mendeleyev's design leaves placeholder spots that clue scientists in to where more work needs to be done as they search for all the elements. Once again, Bryson shows how scientific progress hinges on much more than good ideas—it also relies on elegant, accessible, and inspiring ways of capturing such ideas.

Another defining moment in chemistry's history arises in 1896, when graduate student Marie Curie is tasked with figuring out why her supervisor's uranium salts burned an image (like light rays would) onto a wrapped photographic plate in his drawer. Curie names the effect "radioactivity" and goes on to become the only person in history to win Nobel Prizes in both Physics (1903) and Chemistry (1911). Radioactive material is swiftly commercialized—finding its way into toothpaste and laxatives—before its fatal effects are discovered in the 1930s. Even today, many of Curie's papers are still so radioactive that they're too dangerous to be handled.

Bryson emphasizes Curie's achievement in science—as the only person in history to ever win Nobel Prizes in both Chemistry and Physics—to underscore the profound contributions to science that women are capable of despite being largely undervalued in scientific history due to sexism. The swift commercial uptake of radioactive material shows how humans often rush into using new discoveries without proper concern for the damage they might cause to the environment or to themselves.

Not long after Curie's discovery, the previous chapter's young farm boy, Ernest Rutherford, is studying chemistry in Canada when he discovers that it always takes the same amount of time for half a sample of radioactive material to decay. He realizes that "half-life" could be used to calculate radioactive material's age based on the amount of radiation and rate of decay. When testing his idea on a piece of uranium, he discovers that it's 700 million years old, proving Earth is much older than anyone previously estimated, despite Kelvin's protestations to the contrary. Kelvin later dies still adamant that his greatest contribution to science is his calculation of Earth's age as 20 million years old.

Rutherford's experiment shows that new discoveries leading to new insights are always possible—it's hard to anticipate what's around the corner when it comes to scientific discovery, meaning that everything scientists assume to be true can be changed in an instant when new information comes to light. Bryson thinks that an attitude of openness to this kind of change is essential for scientific progress, which is the exact opposite of Kelvin's response to Rutherford's experiment.

CHAPTER 8: EINSTEIN'S UNIVERSE

By the 20th century, scientists confidently believe they've "pinned down most of the mysteries of the physical world." In 1875, young German scholar Max Planck is even advised to pursue mathematics instead of physics on the basis that there is little left to discover in physics. Nonetheless, Planck studies theoretical physics, only to realize with dismay that his findings on entropy have already been discovered by an obscure retiring American scientist named James Gibbs, whose similar 1875 discovery—that thermodynamic principles also apply at the atomic level—isn't highly publicized.

Bryson leverages the advice that Planck is given to emphasize that overconfidence in the "mysteries" of the universe is a mistake. The advice that Planck receives couldn't be further from the truth, since scientists will soon learn new insights about light that throw everything previously known into question. Bryson implies that no matter how much scientists think they have "pinned down" an issue, there is always more to be learned.

Meanwhile, in the 1880s, American scientists Albert Michelson and Edward Morley prove that "ether"—which was widely embraced by many scientists, including Newton, as an essential invisible substance that permeates everything—doesn't exist. Newton hypothesized that the speed of light pushing through ether would change based on whether the perceiver stood toward or away from the light source. Attempting to measure this "ether drift," Michelson and Morley are shocked to find that their experiments demonstrate light traveling at the same speed in all directions.

Michelson and Morley's experiments provide the first clue that assumptions by physicists of the last two centuries are starting to unravel. This often happens when technological advances enable hypotheses (like Newton's) to be tested for the first time. Michelson and Morley's surprising results show that ether drift doesn't happen, implying that something is off with Newton's claim.

Planck attempts to make sense of the Michelson-Morley experiments in 1900, and he ends up formulating quantum theory. Quantum theory is based on the idea that light doesn't travel as a continuous wave, but in chunks or packets, which Planck named "quanta." Planck's theory revolutionizes the field of physics. Around the same time, an anonymous clerk (with no status or university affiliation) publishes three papers in 1905 that also change the face of modern physics. His name is Albert Einstein, and the papers explain the nature of light as something that travels like both a particle and a wave. They also offer proof that atoms exist and lay out Einstein's famous theory of relativity, which wins Einstein a 1920 Nobel Prize in Physics.

Planck formulates quantum theory—which completely changes the field of physics—less than a decade after scientists claim they have resolved all the "mysteries" of the physical universe. New insights about the behavior of light—as both particle-like and wave-like—contradict Newton's picture of the world, which is taken as fact until this point. Planck's theory thus exposes an important facet of scientific discovery: it's often the case that the more scientists delve into an issue, the more they realize how little they actually know.

Einstein previously struggled in university—he failed his entrance examinations multiple times and eventually took up work as a bank clerk. Nonetheless, he changes the face of modern physics by formulating his infamous E=mc^2 equation, which states that mass (m) and energy (E) are two forms of the same thing, meaning that all physical objects contain latent energy and that mass can be converted into energy. It shows why radioactive objects—like uranium—radiate energy, and it explains why and how stars burn for billions of years (because even a tiny mass creates a much larger amount of energy). The equation also proves that ether doesn't exist, and it shows that the speed of light is constant, universal, and unsurpassable.

Bryson emphasizes Einstein's difficulties in university to show that profound contributions to science can come from people whom scientists might typically overlook, underscoring the importance of guarding against prejudices about the kind of people who are intelligent enough to pursue science. Bryson also stresses the elegance of Einstein's equation, which, in one fell swoop, addresses many unanswered questions about the universe.

Bryson suggests that relativity theory doesn't sweep the public imagination the way other scientific discoveries (like dinosaur fossils) do because it's "just so thoroughly nonintuitive." It argues that space and time are relative to the observer. The most obvious example of this that's applicable to humans occurs with sound: if we move away from a loudspeaker in a park, the sound seems to be quieter. The sound hasn't changed, but our position relative to it has. A snail, however—which can't move away nearly as fast—would not perceive the speaker's volume changing.

Bryson emphasizes that it's especially important for science writers to articulate ideas in accessible ways when science delves into increasingly counterintuitive areas, as it does with relativity theory. Despite the confusing nature of relativity theory, however, it's still possible to render the picture accessible with the use of tangible, accessible examples, as Bryson's loudspeaker analogy shows.

Another implication of relativity is that space and time aren't separate, but interwoven like fabric. Bryson asks the reader to imagine a mattress with a heavy iron ball on it. The **mattress** will sag where the ball is. If one tries to roll a lighter ball across the mattress, it won't roll straight across, but toward the sagging part. Objects in space—like the sun—do the same thing to the fabric of spacetime: they make it sag, so lighter objects roll toward them. The effect that we perceive as gravity is actually warped spacetime, sagging with heavy objects and affecting the paths of lighter objects.

The mattress symbolizes the nature of spacetime, and it shows how sometimes things (like spacetime) that are opaque to laypeople can explain phenomena that are visible to us (like gravity). Bryson once again shows the power of a good metaphor in rendering complex ideas accessible with his illustration of spacetime as something like a soft surface that's punctuated with heavy objects, which affect the paths of other objects on the surface.

Einstein's theory also implies that the universe isn't static, but either contracting or expanding. Soon after Einstein figures out relativity, American scientist Vesto Slipher notices that distant stars appear red. The "red shift" effect implies that the universe isn't static but expanding, because light moving away from humans appears red and light moving toward us appears blue. Unfortunately, Slipher doesn't know about Einstein's theory, so he doesn't realize the significance of red shift. Slipher's discovery has little impact until "a large mass of ego named Edwin Hubble" comes along.

Bryson indicates that scientific insights are often pieced together like jigsaw puzzles from the disparate contributions of different people. Slipher's inability to understand the significance of his discovery shows that science is a collaborative, long-term endeavor: it takes time to make sense of new data, and sometimes existing data needs a new theory for its significance to be recognized.

Bryson describes Hubble as handsome, sporty, and intelligent, though prone to embellishing and exaggerating his achievements. Nonetheless, when a 30-year-old Hubble takes a position at the Mount Wilson Observatory in Los Angeles in 1919, he "swiftly and unexpectedly" becomes "the most "outstanding astronomer of the twentieth century." Hubble wants to know how old the universe is and how big is it. Answering the question requires knowing how far away specific galaxies are (something nobody knows in the early 20th century) and how fast these galaxies moving away from us (which red shift captures).

Bryson describes Hubble's personality as egotistical and prone to embellishment to underscore that Hubble takes a lot of credit for scientific discoveries about the universe, yet he actually leans quite heavily on the contributions of others. Bryson raises the example of Hubble to show that often, the most famous people associated with a scientific discovery obscure the tireless work of undervalued contributors.

The missing piece of information—how to measure the distance of specific galaxies—is figured out by a woman named Henrietta Swan Leavitt, who works as a clerk at the observatory surveying telescope images. She realizes that certain older stars—which she calls "Cepheids"—burn fuel in a consistent pulsing pattern when they reach a certain age (or become "red giants"). Using these "standard candles," as she coins them, the relative distance of other stars can be calculated. As a woman, Leavitt is only permitted to look at smudged photographic images rather than into the telescopes themselves, so Bryson finds her feat remarkable—especially since her boss, William H. Pickering (who can look into telescopes whenever he wants) thinks that the moon's craters are caused by migrating insects.

Bryson exposes how much scientific progress is held back by patriarchal values when he describes the barriers to entry for women in astronomy. Women like Leavitt are often relegated to support roles and denied access to resources like telescopes. Bryson juxtaposes Leavitt's ingenious "standard candle" measure with the absurdity of Pickering's theory about migrating insects on the Moon to show how unjustified sexist assumptions about the capabilities of women are and how much such values limit scientific progress. Had Leavitt been permitted direct access to a telescope, she may well have made many additional contributions to astronomy.

Before 1923, scientists assume that there's just one galaxy—ours—and everything else is distant gas clouds. But when Hubble combines Leavitt's standard candle measure and Slipher's red shift effect, he realizes that a gas cloud in the Andromeda constellation isn't a gas cloud at all, but an independent galaxy 100,000 light years across and 900,000 light years away. The universe is far vaster than anyone ever suspected. (Bryson notes that scientists now estimate there are 140 billion galaxies, meaning if each galaxy were the size of a pea, their total number would fill concert hall.) Then, Hubble realizes—from red shift—that all the galaxies are moving away from us, getting faster as they go.

Bryson shows how Hubble's insights about the size of the universe are dependent upon Leavitt's and Slipher's contributions. Without their insights, Hubble would not be able to realize that the universe is much vaster in scale than anyone could have imagined. This example shows how the important contributions of women like Leavitt to science are often overlooked. Hubble's discovery also shows that humans really know very little about the universe—in fact, it's so incomprehensibly large that there are many things we may never know.

Hubble fails to realize the significance of his finding until a Belgian theologian named George Lemaitre realizes that Hubble's finding confirms that the universe isn't static and eternal. It must have expanded from a single starting point, had a beginning, and might therefore one day have an end—like a firework, as Lemaitre puts it. Lemaitre effectively anticipates the concept of the Big Bang decades before Penzias and Wilson hear a hissing sound in an antenna at Bell Labs and inadvertently discover cosmic background radiation.

Bryson makes it a point to show that Hubble doesn't fully probe the significance of his findings, further underscoring that Hubble takes more than his fair share of credit (much of which is owed to women like Leavitt). Once again, a new insight—here, that the universe is expanding—is completely groundbreaking, since it implies the universe might not have always been here. Bryson thus shows that the more humans learn about the universe, the more we realize how miniscule our knowledge is.

CHAPTER 9: THE MIGHTY ATOM

Everything is made of atoms—tables, walls, the air between us, and even human beings ourselves. Atoms combine to make molecules (he way letters combine to make words. When we die, our atoms disassemble and go off to make other molecules. Every atom in a person's body was once part of a star and of many other creatures. Bryson notes that up to a billion of every individual's atoms came from Shakespeare, another billion from Beethoven, and another billion from Genghis Khan. Atoms are so small that the number of atoms per millimeter is like the number of sheets of paper in a stack as tall as the Empire State Building.

Having emphasized the vast scale of the universe, Bryson now switches tracks to discuss the minute nature of the tiniest particles on Earth. Bryson emphasizes the unimaginably small size of atoms and their components to show that even when the phenomena scientists investigate are right under their noses, there are still countless mysteries to be resolved. Whether scientists scale up (to the universe) or down (to the tiniest particles), a lot of knowledge evades them.

The modern conception of atoms as tiny, numerous, and indestructible is formulated in 1808 by a British schoolteacher named John Dalton, who speculates that elementary particles can't be destroyed. Einstein touches on this issue in a 1905 paper but abandons it to pursue relativity theory. Instead, it's taken up by Rutherford (the same farm-boy-turned-scientist who discovers radioactive half-life and dates Earth's age to over 700 million years). At the time, scientists assume atoms are solid positively-charged objects studded with smaller negatively-charged components (like raisin buns). However, Rutherford shoots ionized particles at a sheet of gold foil, and he's shocked when some sail through (meaning there is empty space in gold atoms) while others bounce back (meaning the atoms have small and dense centers).

Although atoms are hypothesized as early as 1808, it takes almost a century for tangible information about them to be uncovered. Bryson stresses once again that scientific discovery takes a long time—often longer than a lifetime—indicating how much work there is for scientists to do. Rutherford's experiment similarly shows that prior assumptions about atoms as solid objects are wrong, since they contain a lot of empty space. Bryson thus emphasizes how little scientists actually know about the minute particles that make up the fabric of existence.

Bryson explains that every atom contains a dense nucleus packed with protons (positive charge) and neutrons (no charge), that electrons (negative charge) circle around. Bryson illustrate this idea with the idea of a **cathedral with a fly inside**: if the fly represents the nucleus, the electrons are as far away as the cathedral's walls (but since protons are heavier, the fly would be heavier than the cathedral). An atom, therefore, is mostly empty space. The ability of atoms to stay intact seems puzzling: electrons should be falling into nuclei, but they don't; nuclei should blow up, but they don't. The discovery of neutrons in 1932 explains why, since neutrons stabilize the atom's nucleus.

Bryson symbolizes the atom as a fly in a cathedral to help the reader conceptualize the vast amount of empty space that each atom contains. If the cathedral is the size of the whole atom, everything except the space that the fly (nucleus) takes up is empty, meaning the atom is almost entirely comprised of empty space. Once again, this new discovery that atoms contain mostly empty space triggers even more questions (say, about why atoms don't implode), which underscores that the more scientists find out about the world, the less it turns out they actually know.

In 1913, Rutherford's Danish colleague Niels Bohr realizes that electrons appear and disappear—they can jump between different orbits around the nucleus without occupying the space between, a phenomenon he dubs "quantum leap." Scientists also puzzle over why electrons sometimes act like particles and sometimes act like waves. In 1926, Werner Heisenberg proposes—with his famous "uncertainty principle"— that we can know where an electron is *or* the path it will take as it moves, but not both. In simpler terms, Heisenberg shows that we can't predict where an electron will show up around an atom's nucleus. This means that, bizarrely, an atom's nucleus is like a dense cloud of protons and neutrons, surrounded by a field in which the electron will most probably occur.

Bryson shows that the more scientists delve into the world of particle physics, the less sense things make. It turns out that electrons act in completely different ways than anything scientists have witnessed in the universe: they appear to jump in space or to appear and disappear at random. The atom, then, isn't so much an object as an object plus *a field of probability. The unusual behavior of electrons shows just how little scientists understand of the world at this scale.*

Even more strangely, scientists realize that atomic particles have twins, and they act in unison regardless of the distance between them. In order to understand this concept, Bryson asks the reader to imagine a pair of balls: if Bryson spins one clockwise in Ohio, its twin in Fiji will simultaneously spin anticlockwise at the same speed. Further, it seems that physicists need one set of laws for motion in the external world (centering on gravity), and another set of laws for motion in the subatomic world (for which strong and weak nuclear forces are posited). Einstein, in particular, is bothered by how messy this solution is. It doesn't sit well with him to think that God didn't tie the picture together, and Einstein "wastes" half his life trying unsuccessfully to tidy it up.

Bryson reemphasizes how strange, mysterious, and unknown most phenomena are at the subatomic scale, showing that there are many things scientists have yet to make sense of—and likely, also many things that scientists will never *make sense of. Bryson also leverages the example of Einstein to show how religious values can cloud scientific judgement. Einstein's intuition that God would not create a world in which things are unknowable makes him want to reconcile reality with his image of the kind of world that God would create. Einstein's wasted efforts show how religious intuitions can misdirect even the brightest of minds.*

CHAPTER 10: GETTING THE LEAD OUT

In 1921, an engineer for General Motors named Robert Midgley Jr. discovers that a compound called "tetraethyl lead" stops car engines from shuddering. Despite lead's poisonous and deadly effects on humans (it can cause hallucinations that induce death), a conglomerate named Ethyl Corporation begins manufacturing leaded gasoline, which proves a commercial success. Midgley then invents chlorofluorocarbons (CFCs), which find their way into many consumer products and begin burning a hole in Earth's ozone layer at a rate of 70,000 pounds of ozone per pound of CFCs. Bryson explains that ozone is oxygen with three atoms per molecule instead of two, and it soaks up deadly ultraviolet radiation. Ozone is hard to come by, which makes ozone-burning CFCs the "worst invention" of the 20th century by Bryson's estimation.

Bryson raises the case of Midgley Jr. to show how reckless humans can be: CFCs are rapidly taken up commercially and used for years before scientists discover how damaging they are to Earth's ozone layer. The ozone layer is a crucial barrier that protects humans from being obliterated by deadly ultraviolet radiation, meaning that the hasty human drive to industrialize the use of CFCs (without understanding their impact on the atmosphere) threatens our very existence and the existence of all other species. Bryson thus implies that humans can be a direct threat to life on Earth.

By the 1940s, scientists still don't know how old Earth is. A scientist named Willard Libby invents radiocarbon dating—but it only applies to bones, not rocks. Nevertheless, his invention prompts renewed interest in finding a method for calculating Earth's age. Graduate student Clair Patterson knows that Rutherford's half-life measure (of the decay of uranium into lead) can be used to age rocks, but he doesn't know how to identify which rocks of the Earth's rocks are definitely the oldest. Eventually, Patterson tries meteorites, correctly guessing that they'll be as old as the Solar System. He's shocked to find that they are 4,550 million years old.

Bryson revisits the question of Earth's age to show that up until the mid-20th century, everything scientists assumed about Earth's age for 300 years was incorrect—that Earth is much, much older than any scientist had imagined. Once again, Bryson emphasizes both how little humans actually know about the world around us and how many generations it can take to address scientific mysteries, implying that scientific discovery is a vast and likely endless task.

Patterson also has to factor out atmospheric lead. He discovers that before 1923, there was hardly any lead in the atmosphere, and he begins campaigning for lead reduction. Despite losing funding and research positions (at the hands of well-connected lobbyists), Patterson helps to get the Clean Air Act passed in 1970. Many corporations subsequently outsource production to countries where CFCs and lead additives are still legal.

Patterson's attempt to age Earth with meteors shows that humans have been pumping our atmosphere full of lead—which is poisonous to us—without fully understanding how this will affect our ecosystem. Once again, human behavior is exposed as something that recklessly endangers our already precarious existence.

CHAPTER 11: MUSTER MARK'S QUARKS

In the mid-20th century, a British scientist named C. T. R. Wilson is trying to build an artificial cloud formation machine and discovers that subatomic particles leave visible trails in the cloud chamber—meaning he's just accidentally invented the particle detector. Using Wilson's model, physicists start building increasingly advanced and expensive particle colliders, though a number of efforts are halted midway by the U.S. Congress pulling funding. Physicists begin to discover a host of subatomic particles, including the building blocks for atomic particles, the building blocks for those, and so on. These discoveries prompt Carl Sagan to speculate that electrons might themselves contain an infinite regress of mini-universes full of galaxies of subatomic particles.

Wilson's inadvertent discovery enables scientists to more accurately monitor the behavior of subatomic particles. Once again, access to greater information exposes how little humans actually know about the world. Each time we discover a subatomic particle, we also discover even smaller particles that it's made of, implying that there might be countless layers of more and more minute particles that humans may never get to the bottom of. Sagan's speculation shows that there are things humans will likely never know about the world at this scale.

In the 1960s, American physicist Murray Gell-Man attempts to render the 150 or so known subatomic particles a bit more comprehensible. Gell-Man hypothesizes that all atomic particles are made of "quarks," which are divided into six categories and three colors. Gell-Man's system prompts the development of the "Standard Model" of sub-atomic particles and forces needed to build protons, neutrons, and electrons. Finding the Standard Model too unwieldy, physicists develop "superstring theory" to help simplify the picture. Superstring theory postulates that subatomic particles are actually strings that oscillate in 11 dimensions—the three that humans know, plus time and seven others that we don't know. Hypothesizing multiple dimensions helps physicists bring together quantum and gravitational laws into one picture.

The scientific picture gets increasingly unwieldy as particle physicists discover more and more subatomic particles. Gell-Man's project emphasizes that there is a need for new discoveries to be articulated or expressed with clarity in order for science to keep progressing in a decipherable way. This is especially true when science gets as complicated as it is for particle physicists. The development of superstring theory unfurls even more potential realms of existence that humans may never know about, including dimensions that we can't access.

Bryson thinks that efforts to simplify particle physics cause more problems than solutions, as superstring theory formulates convoluted descriptions of the universe. "M Theory," superstring theory with membrane-like surfaces added, is similarly obtuse. For Bryson, physics has reached the point of becoming indecipherable because it's nearly impossible to discriminate between genius and hoax theories—even among physicists. Matters in astronomy become similarly unwieldy. Hubble formulates an equation for estimating the universe's age, but it yields an answer of two billion years, which is problematically younger than the Earth's true age. Astronomers also discover that "standard candles" are more variable than anticipated. Additional challenges include the costly nature of telescope use (especially for distant objects), the difficulty of assessing distance from light readings, and a scarcity of evidence.

When there are many unknown variables, scientists are forced to speculate and posit hypothetical entities (such as superstrings with membranes). Bryson warns against science lapsing into a space that's so hypothetical that it fails to connect with reality in a meaningful way. In such cases, Bryson believes that scientists should be extra careful about the way they describe or express things in order to help keep the scientific endeavor on track and stop it from lapsing into absurdity. This is especially the case for areas in which scientific knowledge is so limited that theorizing becomes a matter of pure speculation.

Physicists also question the universe's size. One recent theory suggests that distant images telescopes capture are illusions—reflections of closer objects. Also, physicsts can also only account for a fraction of the universe's matter, meaning most of it is held together by dark matter, which is invisible to humans. Debates also abound among WIMPs (who factor in invisible particles from the Big Gang) and MACHOs (who factor in black holes), others who factor in dark energy as well as dark matter, and others still who factor in subatomic particles that appear and disappear in infinitesimal components of a second. Bryson notes that when it comes to the universe, the most we know is how little we actually know.

Bryson stresses that humans know very little about the universe by discussing phenomena in space that we have little to no grasp on—such as dark matter, which permeates everything but is undetectable by humans. Whether scientists scale up (to the universe at large) or scale down (to the tiniest particles that exist), the picture is increasingly complex and mysterious. All of this implies that the harder and closer scientists look, the more they realize that there is so much that humans don't know and may never know.

CHAPTER 12: THE EARTH MOVES

In 1955, Charles Hapgood argues that continental drift—the theory that Earth's landmasses are in motion—is a hoax. He's arguing against a growing body of scientific work which suggests that the continents originated as a single landmass but have since split and moved. This is based on evidence ranging from the shapes of coastlines to the presence of identical rocks and fossils on both sides of the Atlantic.

Bryson raises the example of Hapgood to show that scientists are often slow to accept new hypotheses, even if the evidence is right in front of them. Bryson intends to show that dogmatic resistance to new ideas among scientists can dramatically slow down scientific progress.

The first credible scientist to advance the idea of continental drift theory is German meteorologist Alfred Wegener, whose work comes to prominence in the years following World War I. In this era, the geological community is at pains to find a theory of how land moves over time that can account for confusing phenomena, such as the varying ages of mountains. The prevailing theory at this time is that land moves, but only up and down, so theoretically all mountains should be roughly the same age. Despite the explanatory power of Wegener's claims, geologists dismiss them; Wegener is a meteorologist, after all, with little geological training. To explain away Wegener's ideas, geologists invent bizarre theories without evidence, such as the prehistoric existence of land bridges between continents that allowed animals to migrate across oceans.

Wegener is the first scientist to realize Hutton's early (and correct, but overlooked) geological intuition that mountains are made by giant land masses smashing into each other. Wegener's theory that continents drift together and apart makes good sense of a lot of confusing data—for example, why the same fossils are found in disparate parts of the world or why mountains aren't all the same age. Nonetheless, many geologists are resistant to Wegener's ideas because they are prejudiced against the insights of non-specialists, even if the insights make good geological sense.

Wegener's theories begin to gain traction only in the mid-40s after English geologist Arthur Holmes theorizes *how* continents move: radioactive warming from deep inside Earth causes convection currents powerful enough to move land masses. This basics of this theory are still accepted today.

Bryson shows that it takes several years for Wegener's ideas to be accepted by geologists, showing how much dogmatic resistance to new ideas can slow down scientific progress.

Meanwhile, mineralogist and naval officer Harry Hess discovers during World War II (from military surveying equipment on his ship) that the ocean floor contains canyons, trenches, and Earth's most extensive mountain range. These mountains, the mid-Atlantic ridge, stretch south from Iceland down below Africa, on to Australia, and across the Pacific to California. Oceanographers also realize that the ocean floor is much younger where the mid-Atlantic range is, but they're puzzled as to why.

Hess's findings show once again that the more data scientists uncover (say, about the young age of the mid-Atlantic ridge) the more they realize how limited and erroneous their knowledge is (in this case, about how mountains are formed). This is especially true for Earth's oceans, which are some of the most under-explored spaces on Earth.

Meanwhile, British graduate students Patrick Blackett and S. K. Runcorn also discover that the direction of iron particles in British rock are facing the wrong way. Iron particles in rocks line up with Earth's magnetic poles when the rock is formed, but the iron particles in the rocks they discovered weren't facing the right direction—meaning that Britain has moved to where it is from somewhere else. Their findings, however, are largely ignored until British geophysicists Drummond Matthews and Fred Vine combine all these ideas to conclude that the sea floor is spreading apart and that continents are in motion, giving rise to "plate tectonics."

Despite the fact that evidence in support of continental drift keeps arising across the world (including the direction of iron particles in rocks), many scientists are still close-minded about the idea. Hutton first hypothesizes the idea in the 1700s but fails to express it in a way that anybody could understand, meaning his bad writing significantly sets back progress. When the idea resurfaces in the 20th century, as it does here, geologists are still somewhat dogmatic in their resistance to embracing it—close-mindedness thus also set back scientific progress in this area. The combination of these factors means that it takes over 200 years for plate tectonics research to finally get going.

Although many geologists resist plate tectonics theory well into the 1970s, scientists now hold that Earth's crust is made of up to 32 plates that move in different directions and that modern landmasses moved significantly more than initially estimated. Bryson notes that Kazakhstan, for example, was once attached to Norway and New England. Scientists predict that eventually, California will separate and become a Pacific island, while Africa will push up into Europe, replacing the Mediterranean Sea with a mountain range. The scientific community admits that there are still many unexplained mysteries, like why some places—like Denver and parts of Africa—are rising without tectonic activity at all.

Bryson provides two reasons for why the scientific endeavor is never complete: first, Earth is not a static entity. Things are changing all the time, including the face of Earth's land masses, meaning that ongoing changes will demand scientific analyses as time progresses. Second, theories that explain some phenomena well (say, that mountains are made when tectonic plates smash into each other) still fall short in explaining other phenomena (such as why land masses rise in the middle of tectonic plates, where there is no smashing going on). All this implies that there will always be further need for scientific analysis.

CHAPTER 13: BANG!

In 1912, American water drillers are shocked to find that rocks in Manson Iowa don't resemble the rocks elsewhere in the state. It turns out that 2.5 million years earlier, a mile-wide rock smashed into Manson Iowa, creating a crater 20 miles wide. Subsequent ice ages smoothed it over—erasing signs of a crater—but the impact obliterated the top layer of limestone that populated the rest of Iowa. In the early 1900s, most scientists believe that craters are the result of volcanoes and steam explosions within Earth. This is called into question, however, when a geologist named Eugene Shoemaker discovers anomalous substances in Barringer Crater, Arizona (subsequently renamed Meteor Crater) that suggest an impact from space. Shoemaker thus begins studying the asteroid belt with his colleague David Levy.

Even as late as 1900, scientific knowledge about craters is highly limited since hypotheses about volcanoes and steam explosions are incorrect. Shoemaker and Levy's discovery that meteors have—and often do—crash into Earth exposes how vulnerable our planet is to impacts from the asteroid belt. Bryson leverages his discussion of the asteroid belt in this chapter to introduce the idea that humans tend to be blithely unaware about the precarious nature of our continued existence on Earth.

Asteroid research wanes in the 20th century when astronomers turn their attention to distant galaxies, so it isn't until the early 2000s that a substantive—and growing—log of asteroids passing Earth's orbit starts taking shape. Bryson asks the reader to imagine that Earth is the only car on a giant **freeway** (Earth's orbit) and asteroids larger than 10 meters are wayward pedestrians—at any given moment, there would be over 100 million pedestrians crossing the freeway. Shockingly, about 2,000 asteroids large enough to destroy human life on Earth regularly cross Earth's orbit. Two such near-misses were observed in 1991 and 1993. Some scientists even estimate Earth sees 2-3 such near misses per week—they're just not visible to us until they're too close.

Bryson stresses that scientific data about asteroids is still incomplete, meaning that there's still a lot more scientific work to do in this area. Bryson uses the metaphor of Earth as a car on a freeway to underscore that even though it doesn't seem like it to humans, our planet is whizzing through space at breakneck speed, and it's perpetually dodging obstacles (symbolized by pedestrians) in its way. The sheer magnitude and high frequency of potential collision shows that human life could be obliterated at any moment.

In the 1970s, a young geologist named Walter Alvarez doing fieldwork in Italy becomes curious about a thin band of clay between two ancient layers of limestone. Now named the "KT boundary," this layer marks the extinction of the dinosaurs. At the time, however, most scientists believe that dinosaurs died out gradually. Alvarez's father, nuclear physicist Luis Alvarez, thinks that the clay came from space since space dust regularly settles on Earth—though not as much as in Walter Alvarez's sample. They convince a colleague named Frank Asaro to test the clay, who realizes that it contains 300 times more iridium than normal.

Alvarez's discovery of the KT boundary shows that the perpetual risk of total annihilation by asteroid impact isn't just a hypothetical scenario. The evidence begins to mount that catastrophic asteroid collisions are a very real part of Earth's history—as the Alvarezes suspect—and that the mysterious clay band is a pulverized meteor from space.

Asaro and his colleague Helen Michel start testing samples from different places around the world and discover the iridium layer exists worldwide. The team concludes that Earth must have been struck by an asteroid that was pulverized into a giant dust cloud surrounding Earth, destroying the dinosaurs in an instant. Although the idea of asteroid impact killing the dinosaurs is already floating around (it's hypothesized by several others as early as 1942), paleontologists are still shocked by Walter Alvarez's evidence, as it goes against the more popular view of gradual extinction.

When Asaro and Michel realize that the clay band is a worldwide phenomenon, they realize that an asteroid impact must have spread meteor dust around the world at the same time and killed the dinosaurs in that instant. Bryson's discussion about the extinction of the dinosaurs implies that a similar event could wipe out humans at any given moment, meaning that we really are very lucky that this hasn't happened to us yet.

Walter Alvarez's opponents dispute the claim, saying that there's no evidence of an impact site. This prompts scientists to start hunting for one. Geologists Ray Anderson and Brian Witzke (along with Shoemaker) attribute Manson, Iowa's soil anomalies to a meteor crash, and they think they've discovered the missing impact site buried deep under Manson Iowa. Unfortunately, the data eventually reveals that the impact in Manson happened 9 million years too early. The search continues, and in 1990 Alan Hildebrand learns about a strange ring formation in Mexico's Yucatan Peninsula from a journalist. Hildebrand establishes this as the impact site, though the crater itself is buried under three kilometers of limestone.

The reluctance of scientists to accept Alvarez's data shows that dogmatic belief in a popular worldview—in this instance, that extinction happens gradually—can result in scientists being closeminded about new evidence. The fact that the impact site is buried deep underground shows that scientists—both literally and metaphorically—can't take Earth at face value. A lot of the evidence needed to make sense of Earth's history is buried deep underground, further impinging the ease of scientific discovery about the past.

After this, scientists are still slow to accept that the dinosaurs were killed by an asteroid—many argue that an 80-mile-wide asteroid couldn't possibly trigger worldwide annihilation. Eventually, they decide to observe a comparably sized comet headed for Jupiter in 1994, and they're shocked to that see it creates Earth-sized damage to Jupiter's surface. Sadly, Shoemaker dies before seeing this, but the comet is named after him and his ashes are sent to the moon in a tribute to his research. With this insurmountable evidence, the scientific community finally accepts that the dinosaurs were, in fact, killed by the meteor that struck the Yucatan Peninsula.

Bryson shows that geologists are somewhat dogmatic about their preference for gradual extinction theories—even with a worldwide KT boundary and an impact site, scientists still doubt that an impact like this could have such devastating effects to life on Earth. The comet that hits Jupiter confirms—over 20 years after Alvarez's initial discovery—that the asteroids which regularly cross Earth's orbit are capable of wiping us out in an instant.

Despite being the wrong crater, the Manson Crater becomes a hub for scientific analysis. Bryson asks Anderson and Witzke how much warning humans would have if a meteor (like the one that hit Manson) were to happen today, to which they reply "none": it would be invisible until burning through the atmosphere, approximately one second before impact. Such a meteor would compress the air underneath it, making it grow 10 times hotter than the sun. Everything in that area would "crinkle and vanish like cellophane in a flame." The meteor would vaporize upon impact, radiating a 150-mile wide shock wave at the speed of light.

Bryson takes pains to describe the catastrophic outcome of an asteroid impact—his aim is to instill a very real picture in the reader's mind of what would happen if a meteor crashed into Earth right now. Bryson's use of visual metaphors like cellophane crinkling in a flame helps the reader to tangibly comprehend how perilous Earth's orbit actually is and how defenseless humans would be in the face of an impact.

People outside the impact zone would see blinding flash of light brighter than anything ever seen before, followed by a silent "rolling wave of darkness" moving faster than the speed of sound, flattening a 1000-mile wide area within minutes. People would be "sliced […] by a blizzard of flying objects." After the initial shockwave, earthquakes, volcanoes, and tsunamis would likely be triggered, causing global devastation. Within an hour, Earth would be covered in a black cloud of debris raining burning rock that would set Earth on fire, destroying most life, after which soot in the atmosphere would blot out the sun for years (it took 10,000 years for Earth's climate to normalize after the KT impact).

To dispel any doubt that a meteor striking in one place can have an impact around the world, Bryson describes the domino effect that would follow from an asteroid impact. An impact would trigger natural disasters and debris, and it would fill the entire atmosphere with dark clouds. This means that little, if any, life would be able to survive worldwide. Thus, even a small asteroid impact has the potential to completely wipe out life as we know it. With this in mind, Bryson wants to emphasize how close humans come to being wiped out on a daily basis.

Bryson thinks that if there was a meteor headed our way, humans might try to blow it up. Unfortunately, no warhead or spacecraft could travel fast enough to reach the meteor before it would be too close. Even if we could blow it up, the pieces would still rain down on Earth in radioactive chunks. Asteroid hunter Tom Gehrels predicts we'd need several years' advance notice to safely deal with such an asteroid, but we'd be unlikely to know it was coming until a few seconds before impact. Luckily, Witzke says that these sorts of things only happen once every million years or so. A handful of humans might even survive.

Bryson talks to Gehrels to dispel any reassurance that humans would be able to anticipate and divert an asteroid impact. Gehrels confirms that our current technology limits our ability to defend ourselves in any way against impact—most likely, we wouldn't even see it coming. Witzke offers a sliver of hope in suggesting that a few humans might pull through, but the overall outlook is grim. Bryson stresses all this so that we do not take our existence for granted.

CHAPTER 14: THE FIRE BELOW

In 1971, young geologist Mike Voorhies spots a perfectly preserved rhinoceros skull in the grass in Nebraska while surveying land for a map. Subsequently, he inadvertently discovers what's now called Ashfall Fossil Beds State Park: a dried-up waterhole-turned-fossil-bed that's preserving 12-million-year-old animal bones. Voorhies initially thought that the animals were buried alive, but it seems they died from breathing toxic ash and they sought refuge in the waterhole. Curiously, nobody knows where the ash could have come from until geologist Bill Bonnichsen discovers that it matches a volcano in Idaho. It turns out that under Yellowstone National Park, there is a "huge cauldron of magma" that erupts every 600,000 years or so. Bryson says the last time it erupted was just over 600,000 years ago.

Bryson emphasizes that even without the perpetual threat of asteroid impacts, there are still many dangers on Earth itself that could have catastrophic impacts for life on Earth. Voorhies's discovery shows that this clearly happened in the past. To many humans, it may seem that catastrophic events with species-obliterating potential don't happen on Earth since we've enjoyed a relatively tranquil period since our evolution. However, Bryson wants to emphasize that the reader shouldn't take this for granted, since this could change at any moment.

Scientists know "amazingly little" about Earth under the surface—we actually know more about the sun's interior than we do about Earth's. Earth's center is 3,959 miles deep. Most mines only go a couple miles deep, which is comparable to barely denting an apple's peel. In 1906, geologist R. D. Oldham realizes from the angles of seismic shock waves that the waves are bouncing off something deep and rebounding to the surface. From this, Oldham hypothesizes that Earth has a core. Around the same time, seismologist Andrija Mohorovičić discovers similar shock waves in Zagreb, Croatia that appear to rebound off something between the crust and the core. Eventually, Danish scientist Inge Lehman realizes that Earth must have two cores—a solid one surrounded by a liquid magnetic one.

To help the reader conceptualize the limitations of scientific knowledge about Earth's interior, Bryson says that our below-ground exploration is analogous to barely penetrating an apple's peel. Therefore, claims that we have learned everything we need to know about Earth are ludicrous—there is so much we have yet to explore that we are barely getting started. In fact, scientists still have to estimate what's going on in Earth's interior indirectly, just as Oldham, Mohorovičić, and Lehman did.

Around the same time, Charles Richter and Beno Gutenberg devise a way to measure an earthquake's strength (now known as the Richter scale), though a lot of variables—such as the soil, quake duration, and number of aftershocks—affect the actual strength of an earthquake. The largest earthquake ever recorded on the Richter scale is a 9.5 magnitude quake in Chile in 1960 that also set off a tsunami which traveled 6,000 miles to Hawaii. Bryson thinks that the most damaging earthquake happened in Lisbon, Portugal in 1755. Estimated at a 9.0 on the Richter scale, this quake lasted seven minutes and had three aftershocks, killing 60,000 people. In comparison, San Francisco's famous 7.8 magnitude earthquake in 1906 lasted under 30 seconds.

Humans' limited knowledge about Earth's interior leaves us vulnerable to threats of seismic activity, which are difficult to predict in advance. Like asteroids, a catastrophic event in one area can trigger additional disasters far around the globe (as was the case in Hawaii in 1960). The threat to life from Earth's own interior (as from meteors) is therefore very real. Thus far, history has shown that humans are largely defenseless when it comes to earthquakes.

There are approximately two earthquakes over 2.0 on the Richter scale on Earth every day. They tend to occur where two plates meet, like at California's San Andreas Fault. The longer an interval between quakes on a fault line, the more damaging the next earthquake will be. This is worrying for Tokyo, which sits atop the intersection of three tectonic plates but hasn't seen an earthquake since 1923 (when 200,000 people died). There are also "intraplate earthquakes" that can happen anywhere. In Missouri in 1811, one such quake hits, causing deep fissures from which sulfur poured out. Aftershocks destroyed East Coast harbors. Two subsequent quakes follow, each three weeks after the last. Scientists know little about these except that they're as "random as lightning."

Bryson reminds the reader not to be lulled into a false sense of security about Earth's calm surface. Underneath the core, things are very volatile, and the longer things remain calm on the surface, the more catastrophic the next bout of seismic activity will be. Moreover, this isn't a matter of luck (as with asteroids)—it's inevitable. Scientists know even less about intraplate seismic activity, which could happen randomly at any time. Our knowledge of threats from Earth's interior is thus highly limited, and our ability to cling to life on the planet's surface is much more precarious than most people think.

In the 1960s, scientists try and fail to drill through the ocean floor off Mexico, but they only get 600 feet deep. In 1970, Soviet scientists try the same thing in Russia's Kola Peninsula, managing to get 12 kilometers deep (which isn't even a third of the way through Earth's crust). Everything they discover is surprising: the sedimentary layer is 1.5 times deeper than estimated, the temperature is much higher than anticipated, and rocks that deep are saturated with water (previously assumed to be impossible). Other scientists who interpret waves that travel through the ground also learn about "kimberlite pipes," which are like completely random cannonballs traveling from 120 miles deep at supersonic speed, spewing crystals and pulverized diamonds on the surface.

Efforts to uncover more about Earth's interior—and specifically to penetrate Earth's crust—have, as yet, been unsuccessful, meaning that scientists have a tremendous amount of work ahead of them. The deeper scientists dig into Earth (which so far, isn't very far at all), the more they realize that many of their assumptions about Earth's interior are false, further showing how limited our knowledge is. Moreover, the more humans uncover, the more threats to our safety we discover (such as kimberlite pipes), which shows that humans and all the other species living on Earth's surface are even more vulnerable than we may ever know.

Effectively, Bryson says, we know "very little" about Earth's interior. So far, scientists assume that there are four layers: a rocky crust, a mantle of "viscous" rock, a liquid outer core, and a solid inner core. They know that the interior is heavier than the crust, and that somewhere inside is a "concentrated belt" of liquid metallic elements which account for Earth's magnetic field. Everything else is a matter of "uncertainty." Scientists know nothing about how the layers interact nor why the crust is much more variable in thickness than typically estimated. Geologists also disagree on how and when the crust originally formed. Viscous rocks move both horizontally and vertically, creating convection currents that move tectonic plates.

Nearly everything scientists know about Earth's interior—even what it's made of or how many layers of matter there are—is entirely speculative. Even when it comes to the crust, which we can see, scientists face many mysteries, such as why the crust's thickness is variable or when it formed. Bryson emphasizes all this to say that humans know barely anything about the ground beneath us, meaning that scientific inquiry in this domain is still in its infancy.

CHAPTER 15: DANGEROUS BEAUTY

In the 1960s, a man named Bob Christiansen, who works for the United States Geological Survey, is confused to find no evidence of a volcano in Yellowstone National Park. This is odd because volcanic activity accounts for the park's geysers and hot springs. When most people envision a volcano, they think of cone-shaped volcanoes like Japan's Mount Fuji—but there's another, more explosive type called a "caldera" which burst so quickly that they just leave a subsided pit behind. This kind of volcano is what Christiansen is looking for. By chance, NASA had recently sent some high-altitude pictures of Yellowstone to the park officials, and Caldera is shocked when he sees them—he realizes that the entire park is a caldera that's 40 miles wide, making Yellowstone a supervolcano.

To emphasize how perilous life on Earth is, Bryson discusses calderas, or supervolcanoes, like Yellowstone, which are so massive that they can only be seen from space. Even if we think we've identified the dangerous spots on Earth—like active volcanoes and fault lines between tectonic plates—there are still many others that may not be visible to us. A eruption from a caldera the size of Yellowstone would likely have devastating impacts on Earth's life forms, yet this volcano was only discovered in the 1960s. The fact that this discovery was so recent reinforces the idea that human knowledge about Earth is highly limited.

Bryson says that essentially, Yellowstone's visitors are walking on something with the explosive power of an eight-mile-high pile of TNT the size of Rhode Island. Yellowstone sits on a "superplume"—a vast bowl of unstable magma that can burst explosively or pour out a fast-flowing "flood" of molten rock. There are about 30 active plumes on Earth, but the others are all in the ocean. They're responsible for creating most of the world's island chains, including Hawaii, the Galapagos, and the Canaries. Nobody knows why Yellowstone's superplume is on land. It means that Earth's crust is very thin there and that it will likely burst explosively rather than bubbling out slowly.

Bryson stresses the dangers of sites like Yellowstone by comparing them to massive bombs waiting to go off. He describes unstable magma and explosive molten rock floods to help the reader visualize that when Yellowstone next explodes, life around it will be completely defenseless. Furthermore, the fact that Yellowstone is on land instead of under the sea remains a mystery, showing how little scientists know about this phenomenon and the threat to life that it bears.

Scientists know that the Yellowstone supervolcano erupted 16.5 million years ago, and it's blown up about 100 times altogether. There's nothing comparable to this in human experience. The closest comparison to be made is with Krakatau in Indonesia, which erupts in 1883 with a bang that "reverberate[s] around the world for nine days" and ejects golf-ball sized lumps of molten rock. Yellowstone, however, would eject something more like car-sized molten rock chunks. 2 million years ago, a Yellowstone eruption expelled enough debris to bury New York State 67 feet deep in ash. The eruption covered nearly the entire United States, likely destroying the soil for years to come.

Bryson emphasizes that the scale of a supervolcano eruption far exceeds anything humans have experienced. He wants to show that even the worst catastrophes in human history so far come nowhere near to capturing the threats we face from volcanic activity at every passing moment of the day. Even if a person isn't near the eruption site, the effects on soil and the atmosphere would make life even less sustainable than it already is. It really is a matter of luck that none of this has happened to us so far.

Another supervolcano eruption in Sumatra 4,000 years earlier triggered at least six years of "volcanic winter." Scientists think that the altered climate probably all-but-destroyed humans then, probably reducing the global population to a few thousand. Some evidence suggests that it takes 20,000 years for the human population to grow larger again. In 1973, the park develops an "ominous bulge" before swelling and subsiding again over the next 20 years—and geologists realize that Yellowstone isn't dormant but active. They estimate an eruption happens every 600,000 years. The last one was just over 600,000 years ago. "Yellowstone, it appears, is due," Bryson warns.

Bryson emphasizes that although human life hasn't witnessed a Yellowstone eruption, the threat is imminent because Yellowstone is active. Once again, it's not a matter of chance (like an asteroid impact). Rather, it's inevitable that Yellowstone will erupt (probably soon)—meaning that human life faces a very real, imminent threat. Bryson thus reinforces the idea that humans should be in awe of the planet's power.

Bryson asks Paul Doss, Yellowstone National Park's geologist, when he thinks Yellowstone might erupt, but Paul Doss says it's hard to know. Italy's Mount Vesuvius was active for 300 years but stopped in 1944, and nobody knows why. There might be seismic shocks beforehand, but Yellowstone already gets about 1,200 of those a year. In 2000, an organization called "YVO" is created to study Yellowstone's activity and draw up a "hazard plan" in case it blows. Doss hopes that they'll come up with one soon. Of course, it might take another 10,000 years for Yellowstone to erupt, or it might not erupt at all.

Doss's discussion with Bryson shows how unprepared humans are for such a catastrophe, meaning—as with potential asteroid impact—when the next one happens, we'll have no defenses. Even when humans know a catastrophe is imminent, we are still highly vulnerable due to the insurmountable scale of the disaster. Bryson emphasizes that our knowledge is limited to knowing that Yellowstone is due to erupt, but on the geological scale this could mean tomorrow or in thousands of years. Thus, our knowledge in anticipating this event more specifically is also limited.

Bryson points out that there are also other dangers in Yellowstone: in 1959, for instance, a 7.5 magnitude earthquake collapses an entire mountainside, creating a massive landslide that kills 28 campers. Yellowstone, it turns out, it also an earthquake fault zone. To Bryson, the "grandeur and inexorable nature of geological process" is evident in the Teton mountains, just south of Yellowstone. They've been growing six feet per year from tectonic plate activity every 900 years. The last time that happened was 6,000 years ago, so they're "overdue" as well. Hydrothermal explosions are also a concern: Yellowstone has 10,000 geysers, which is more than the rest of the world combined, and they explode without warning.

To reinforce the idea that humans face perpetual threats to our existence, Bryson lists other dangers—beyond a caldera explosion—that are evident in Yellowstone, citing seismic activity and hydrothermal explosions, both of which humans are highly vulnerable to. Worse still, scientists have little to no grasp on predicting when such events will happen, meaning that scientific knowledge about Earth's interior is not just limited—it barely exists.

In 1965, husband-and-wife biologists Thomas and Louise Brock discover—to their surprise—living microbes in some of the scum around Emerald Pool, one of Yellowstone's pools of boiling water. Before their discovery, scientists believed that no life could live in sumptuous, acidic environments at that temperature. Meanwhile, scientists begin finding even tougher microbes that need to live in very hot environments. Now, scientists are no longer sure what the upper limit to sustain life is. Life, it seems, is more "clever and adaptable than anyone had ever supposed."

The Brocks' discovery of microbes that can survive in conditions previously thought to be inhospitable to life shows that scientific knowledge in biology—as in physics and chemistry—is limited. The more creatures that scientists discover, the more they learn that their prior assumptions are false. The fact that microbes can exist in such conditions at all also shows that life's ability to thrive is astounding: it continues to crop up in the most unlikely places.

CHAPTER 16: LONELY PLANET

Being alive isn't easy. As far as humans know, it's only possible to be alive on Earth—buried in a remote corner of the Milky Way—and the zone that sustains life on Earth is only 12 miles high from the ocean floor to the atmosphere, which seems tiny compared to the "cosmos at large." It's even worse for humans since we need to live on land, meaning that 99.5 percent of Earth's volume is off-limits to us. We can climb 500 feet high easily, but 500 feet underwater the pressure would compress our lungs to the size of a soda can.

In addition to the perpetual threats of meteor collisions and natural disasters, humans are also vulnerable because we can only survive in a very small portion of Earth's surface. We know that there are no other hospitable living environments we can access in space, so Earth is all we have—and even then, we only have a small portion of it. Our presence on Earth is thus both rare and precious.

Umberto Pelizzari holds the world record for free diving, at 236 feet deep. Other organisms do survive at much deeper depths. The pressure at the deepest part of the ocean, the Mariana Trench is like standing under 14 cement trucks. Curiously, the human body itself—which is made mostly of water—wouldn't be crushed, but the gases in our bodies would make our lungs implode. Until recently, scientists thought that this would happen to anyone diving below 100 feet, but free divers have proven otherwise.

Bryson emphasizes that humans don't have many places to go on Earth by showing how inhospitable deep water is to human life. Our bodies simply aren't made for the water, despite the fact that it makes up most of the planet's surface. The risk to human life of exploring such depths means that scientists don't even know how deep we can go, further emphasizing the limitations of human knowledge.

The real danger comes from nitrogen, which comprises 80 percent of the air humans breathe. Under deep pressure, nitrogen turns into bubbles that migrate into our blood and tissues. If a diver ascends too quickly, the bubbles start to fizz—just like soda or champagne does—and clog the blood vessels, depriving them of oxygen. Divers call this excruciatingly painful sensation "the bends." The only way to avoid the bends is to dive in and out so quickly that nitrogen bubbles don't have time to form—this is what free divers do. The other solution is to ascend slowly, letting the bubbles dissipate gradually.

Bryson describes the risks that an underwater poses to land mammals in order to underscore that most of Earth's surface is off-limits to humans, meaning the little space we have to inhabit is highly valuable. Deep-water exploration is also limited because few people are willing endure the risks of being so far underwater, meaning that scientific knowledge of the deep oceans is dependent on the direct experiences of a few brave divers and indirect data.

In the early 20th century, the eccentric father-and-son scientists and divers John Scott and J. B. S. Haldane work out the rest intervals needed for a safe. The Haldanes acquire a decompression chamber so they can test what happens to the body at different pressures. When John tries simulating a dangerously fast ascent, the dental fillings in his teeth explode. His wife, whom he coaxes in next, has a 15-minute seizure. Curiously, another effect is nitrogen intoxication. At certain pressures, nitrogen is intoxicating, like alcohol, though nobody knows why. Bryson says all this means that it's pretty hard for a human to leave the surface world.

To emphasize how inhospitable life under water is to humans, Bryson discusses John Scott and J.B.S. Haldane's experiments, showing that ocean pressures make the human body shut down and the human mind dysfunctional. Bryson thus reinforces the idea that humans have nowhere else to go but Earth's surface, meaning that it's extremely risky to knowingly damage our environment.

Human bodies aren't particularly robust: we're sensitive to heat and cold such that deserts and ice caps are off limits. In fact, humans can only really live on 12 percent of the total land area and four percent of the whole surface (including the seas). Nonetheless, there are worse places to call home. If we want another home, we'd need four things.

Even with deep oceans off limits, the human body is also vulnerable in many of Earth's surface environments, including deserts and ice caps, further rendering the space that we do have on Earth highly valuable.

The first thing humans would need for another home is an excellent location: "the right distance from the right sort of star" that burns slowly and keeps us alive but doesn't boil us. In fact, if Earth's orbit were five percent nearer to the sun, everything would be boiled away. If it were 15 percent farther away, it would be frozen over. Second, we'd need the right kind of planet. Earth's molten core created its atmosphere and its crinkly crust—without those, Earth's surface would be smooth and covered evenly in water, meaning only sea life would evolve.

The fact that Earth can sustain human life at all is a matter of sheer cosmic luck—had Earth been fractionally closer or farther from the sun or different in its internal composition, life would have been unsustainable or humans would have failed to evolve. All of this means that on the cosmic scale, human life is very rare and very lucky.

The third thing we'd need for another home is a "twin planet," which for us is currently Earth's moon. The moon happened to be created by an asteroid impact that sent part of Earth into orbit around itself, so it's much larger than it would be otherwise. According to Bryson, the gravitational pull of the moon stops Earth from wobbling on its axis with "goodness knows what consequences for the climate and weather." Finally, we'd need good timing. If history hadn't played out just the way it did—say, if the dinosaurs hadn't been wiped out—we wouldn't be here.

Bryson emphasizes what a chance occurrence it is that Earth is hospitable to human life by showing that had meteor impacts not happened at the precise times in history that they did, humans would likely not exist at all. All this implies that human existence on Earth is not inevitable—if anything, it's more like an extraordinary (and very lucky) accident.

Oxygen is the most abundant element on Earth, making up 50 percent of Earth's crust. The quantities of the rest are "often surprising." Silicon is the second most common element, although the abundance of an element doesn't necessarily relate to how important it is. Carbon only comprises 0.05 percent of Earth's crust, but without carbon, life wouldn't be possible. Other elements are critical for sustaining (rather than creating) life, such as potassium and sodium. Humans evolved to be compatible with naturally-occurring elements, but there are still very "narrow ranges of acceptance." Selenium is essential, for example, but too much of it would kill us. Normally, our tolerance for an element is proportionate to its abundance in Earth's crust.

Of course, part of the reason that humans exist is because we evolved to adapt to this environment, so it's not all a matter of blind luck. That notwithstanding, we still can only survive within a very precise elemental environment—comprised, for example, of specific ratios of potassium and sodium. All this means that if anything were to change in the chemistry of Earth's crust or atmosphere (say, by our burning through the ozone layer or by pumping our atmosphere full of toxic substances), the planet would no longer be habitable for humans.

Element properties become more "curious" when they're combined. Sodium explodes in water "with enough force to kill," and chlorine is lethal—but when combined, these two elements make ordinary table salt. On the whole, humans tolerate elements that are water-soluble. Lead is poisonous because we weren't exposed to it at all before it was used commercially, and plutonium—which comes from space—is 100 percent toxic to us. Other life forms might depend just as vitally on ammonia or mercury but find oxygen deadly if it doesn't naturally occur on their planets. Of course, humans evolved to tolerate the elements around us, so it's not all a matter of luck—but we'd likely be lost elsewhere in the universe.

Bryson emphasizes that although humans can tolerate water-soluble substances, we frequently saturate our ecosystem with elements that are toxic to us. The example he cites is lead, which was nearly absent from the atmosphere before the 20th century but is abundant in it now due to human commercial activity. It's bizarre to Bryson that we threaten our delicate ecosystem so recklessly—such actions are even more risky considering that humans would be highly unlikely to find another environment that we can tolerate. Nonetheless, we continue to flagrantly abuse the only environment we know of that's hospitable to us.

CHAPTER 17: INTO THE TROPOSPHERE

Without the atmosphere, Earth would be frozen over. Its "gaseous padding" also protects us from deadly objects in space, and without its drag, raindrops would knock us unconscious. Surprisingly, the atmosphere isn't all that vast. If Earth were the size of a desktop globe, the atmosphere would be as thick as a couple coats of varnish. The atmosphere has four layers: troposphere, stratosphere, mesosphere, ionosphere (or thermosphere). The troposphere is the most vital to us. It rises from ground level up to 7-10 miles high, and it contains all the water and weather we need. Beyond that, Bryson says, is "oblivion."

Bryson addresses Earth's atmosphere to emphasize how delicate it is and how essential it is to human survival. Humans can only survive in the first level of the atmosphere (the troposphere), which is essential for our climate. Anything beyond the narrow band of the troposphere is inaccessible to us, meaning that humans can neither descend too far (into the oceans or underground) nor ascend too far (into the atmosphere).

The stratosphere comes next: its boundary is marked by clouds flattening out. In 1902, Léon-Philippe Teisserenc de Bort discovers the stratosphere while traveling in an air balloon, though humans can't survive up there because it is oxygen-deprived and -70°F. Beyond the troposphere, the temperature rises again (due to ozone) and then plummets to -130°F, before rising to 2,700°F in the thermosphere. Temperature marks the density of molecules in the atmosphere: it's warmer at sea level because there are lots of molecules bumping into each other and creating heat. Higher up, the molecules are sparser. When "hopelessly ground-hugging" humans ascend too far, the sparseness of molecules can cause confusion, nausea, hypothermia, and frostbite.

Bort's experiments show that life beyond the troposphere is impossible for humans, since we can't survive at the temperatures sustained farther out in the atmosphere. In fact, the higher up humans go, the less oxygen there is, underscoring the extent to which we are limited to Earth's surface, which Bryson believes we should treat much more carefully than we do. Humans require a very specific density of molecules in the atmosphere to survive, a condition that only exists a few miles into the atmosphere. This shows, once again, how limited our tolerance of the universe at large is.

Mountaineers call the area above 25,000 feet the "Death Zone," though altitude sickness sets in above 15,000 feet. Humans can't tolerate living above 18,000 feet (fetuses, for example, can't survive pregnancies at those altitudes due to oxygen deprivation). In the 1780s, experimental balloon ascenders assume it's hotter higher up because they'll be closer to the sun, but it turns out that the sparsity of molecules actually makes it colder. On a hot day, when one feels the sun on one's back, this isn't actually the sun's heat—rather, the heat is generated by excited molecules that are moving faster and colliding more.

Bryson discusses the "Death Zone" to reemphasize how much of Earth's surface is off limits to us—specifically, we can't dwell at high altitudes for extended periods of time. Experimental balloon flights also show that scientific speculation is often fallible, since our prior assumptions about the temperatures in the outer atmosphere are disproved by this ascension.

Air seems weightless, but actually it's quite heavy. For instance, changes in air pressure can pile an extra half-ton of air on a sleeping person, but they won't feel it because their body presses back on the weight and finds equilibrium. Storms expose air's mass more adequately—when air picks up speed, it can destroy everything in its way. Particles in storm clouds pickup electric charges. Scientists don't know why, but lighter particles become positively-charged and heavier particles (at the base of clouds) become negatively-charged. Negatively-charged particles are drawn toward the positively-charged Earth, which is what creates lightning. A bolt of lightning travels at 270,000 miles per hour and heats the air around it to 50,000°F, which is hotter than the sun's surface.

Bryson discusses weather to explain that even the air in the atmosphere that we can tolerate is deceptive—when air moves quickly enough, it's life-threatening. Similarly, the atmosphere we can tolerate is deadly to us once it picks up an electric charge. Bryson further exposes the limitations of scientific knowledge by stressing that scientists have a limited grasp of why storm clouds pick up electric charges in the first place, showing once again that scientists have much to learn about the world around us.

Humans didn't know much about the atmosphere until aviation took off. Clear-air turbulence, for example, is a random and undetectable pocket of lively air cells in an otherwise calm sky. We have no idea what causes it. More generally, convection causes air currents. Moist, warm air rises until it hits the top of the troposphere and spreads out, cooling as it goes. The cooling makes the air sink, and at ground level it spreads out into the low-pressure spaces that hot air has just left before warming and rising again. At the Equator, weather is the most stable and predictable; elsewhere, it's far more erratic.

Even when the skies are calm, there are phenomena that scientists can't explain, such as clear-air turbulence. Part of the reason why humans know so little about the atmosphere is because we've only been able to travel at high altitudes in very recent history. All this reinforces the idea that scientific knowledge of the atmosphere is in its infancy, and it has a long way to go.

The sun's heat is unevenly distributed, causing differences in air pressure. The atmosphere tries to create equilibrium, which causes wind. Halley first predicts this mechanism in the 1600s, though it takes until 1835 for an engineer named Gustav-Gaspard de Coriolis to work out the details (which is why we now call the mechanism the "Coriolis effect"). Meteorology only takes off as a science in the 19th century, after Dutch instrument maker Daniel Gabriel Fahrenheit invents the first thermometer in 1717 and devises the Fahrenheit scale (which puts freezing at 32° and boiling at 212°). In 1742, a Swedish man named Anders Celsius devises a competing (and more intuitive scale) running from zero to 100.

Bryson again emphasizes how recent our knowledge of the weather is, since adequate tools to measure the weather didn't exist until the 1700s. Scientific discovery is often limited, as it is here, by technology. Once sufficiently accurate technology develops, however, it's important for the measurement systems scientists devise (like the way they express their theories) to be clear and accessible. Bryson implies that Celsius's temperature scale, for example, is more intuitive and therefore better than Fahrenheit's scale.

The "father of meteorology," however, is an English pharmacist named Luke Howard, who names the cloud types in 1803. His system divides clouds into three groups: stratus (layered clouds), cumulous (fluffy clouds), and cirrus (high, thin, feathery clouds). A fourth term, "nimbus" identifies rain clouds. Bryson thinks "the beauty of Howard's system" is that the terms can be combined to account for every type of cloud, such as "cirrostratus" or "cumulonimbus." Though Howard's system has been expanded upon over the years, many of the newer cloud names (like "mammatus" and "mediocris") haven't caught on outside esoteric scientific circles. Incidentally, the expression "on cloud nine" comes from cumulonimbus, the ninth and fluffiest cloud in the system.

Bryson further emphasizes the importance of clear and accessible frameworks for making sense of scientific phenomena when he discusses the "beauty" of Howard's system, which is manageable and flexible, and it accounts for a lot of phenomena without being confusing. Subsequent efforts to render Howard's system more specific end up being too convoluted to catch on. Bryson stresses this to show that clear expression is an essential part of facilitating scientific progress, which applies as much to systems of classification as it does to other aspects of scientific communication.

About 60 percent of rainwater returns to the atmosphere within a of couple days through evaporation, though some goes down into ground water and may take thousands of years to return to the sky. Water molecules live in lakes for about a decade before evaporating and for about 100 years in the ocean. Evaporation itself is a fast process. About six million years ago, continental movement closed the Strait of Gibraltar, and the entire Mediterranean dried up in just 1,000 years. The evaporated water fell as freshwater rain in other oceans, reducing their salinity and making them freeze more, triggering an ice age. As Bryson puts it, "a little change in Earth's dynamics can have repercussions beyond our imagining."

Bryson shows that even though there are numerous factors contributing to the precarious nature of life of Earth—including asteroids, geological activity, and climate—there are even more factors to consider when scientists think about the ways in which these factors interact. The combination of precipitation and continental movement can dry up oceans and trigger ice ages, showing how vulnerable humans are to the whims of the planet and how lucky we are to have enjoyed a tolerable climate thus far.

Oceans are also important in meteorology, since rising and falling water molecules (saltier water is denser and falls) create ocean currents, moving water around that subsequently heats and rises as air, with huge effects on Earth's climate. Changes in salinity, for example, can trigger ice ages. Oceans are also essential for creating stability on Earth. The sun burns 25 percent brighter than it did when the solar system was young, and it should have had "catastrophic" effects on Earth—but tiny marine organisms capture carbon dioxide in rainfall and use it to make their shells, preventing the element from rising back up into the atmosphere and creating a worse greenhouse effect that would warm the planet to disastrous effects.

Bryson emphasizes the extent to which human existence depends on other creatures—for example, tiny marine organisms that that absorb carbon dioxide and prevent Earth from overheating to a temperature that can't sustain life. Bryson's motivation is to prompt the reader to question how recklessly humans treat the ecosystems of other creatures. Even if they seem remote or insignificant, even the slightest changes could severely impact our ability to survive.

Before industrial activity, the atmosphere's carbon dioxide level is 280 parts per million. By 1958, it rises to 315 parts per million, and today it's over 360 parts per million. Scientists predict that by the end of the 21st century, it will be 560 parts per million. Earth's oceans (and forests, which also absorb carbon) are effectively saving us from ourselves, but if we cross over a certain threshold, plants will die and release their carbon, rendering life unsustainable. Luckily, Earth is remarkably good at returning itself to a stable state. The last time this happened, it took only 60,000 years.

Bryson shows that human-caused pollution is on the brink of catastrophe that could render life unsustainable. So far, the effects of industrial activity have been masked by the carbon-absorbing life forms on Earth, but if carbon levels rise too high, humans won't even be able to rely on them. The planet itself will be fine, but life as we know it will not. Bryson wants the reader to question why humans endanger themselves by wreaking havoc on our already fragile environment.

CHAPTER 18: THE BOUNDING MAIN

According to Bryson, water is a remarkable substance—and it's everywhere. Humans are 65 percent water, cows are 74 percent water, and tomatoes are 95 percent water. Most liquids contract when they cool, and water does too, by about 10 percent—but, extraordinarily, it then starts to expand. Once water is solid, it's 1/10 as voluminous as it was as liquid. This "beguiling" property makes it float on water instead of sink. Without surface ice, too much heat would leave the oceans, and eventually they'd freeze solid. This means that ice is what effectively keeps the oceans warm and liquid. Water's chemical formula is H2O, meaning that it has two hydrogen atoms and one oxygen atom in each molecule of water.

Bryson wants the reader to marvel at how wondrous the planet we live on is, as emphasized by the fact that water comprises most living things—in addition to possessing chemical properties that prevent the oceans from freezing over. Water, it seems, is essential to life in many different ways, and it's astounding that one substance is capable of performing all the tasks it does to facilitate human life.

Humans would be lost without water: after a few days with no water, our lips vanish and our skin contracts so much that we can't blink. Yet most water on Earth is poisonous to us because of the salt inside it. Strangely, we sweat and cry salty water, but we can't ingest it—when we have too much salt in our body, water molecules leave our cells and try to dilute and expel the salt, which makes us dehydrated, triggering brain damage and death. This is why we can't drink sea water, which comprises 97 percent of Earth's water. Most of the rest exists as ice sheets (like Antarctica). Only 0.036 percent of Earth's water exists in lakes and rivers, and 0.001 percent exists as water vapor in the air.

Bryson emphasizes both how essential water is to human survival and how little usable water humans have access to on Earth. It might seem that water is abundant because of Earth's plentiful oceans, but in fact, only a tiny proportion of that water is consumable because too much salt is toxic to humans. Bryson raises this point to dispel the misconception that humans can afford to be careless with water because there's so much of it on Earth.

Scientific interest in the oceans only picks up in the 19th century. In the 1830s, British naturalist Edward Forbes surveys various ocean beds and concludes there's no life below 2000 feet because there's no light down there. In 1860, however, scientists are shocked to discover clams encrusted on a transatlantic telegraph cable that's been hauled up for repairs from the ocean floor, triggering a worldwide ocean survey expedition by 240 scientists in 1872. Most insights about the sea, however, come from amateurs. In the 1930s, for example, deep-sea divers Charles William Beebe and Otis Barton invent a "bathysphere"—a precarious deep underwater chamber that hangs at the end of a long cable. They use soda lime cans to absorb carbon dioxide expelled by their bodies.

Bryson once again alludes to how recent most scientific discovery is—ocean exploration doesn't even get going until the late 1800s, meaning that scientists have barely had a century to formulate theories about it, and so we still have much to learn. Once again, when it comes to the more challenging of Earth's environments, sometimes scientific discovery hinges on the insights of daring amateurs. This fact further underscores the need for science to be accessible to non-specialists in order to drive progress forward.

Barton subsequently discovers sea life at depths that were previously assumed to be inhospitable to life. Father-and-son divers Auguste and Jacques Piccard also devise a deep-sea vessel in the 1950s, allowing them to successfully descend seven miles down to the deepest point on Earth: the floor of the Mariana Trench. This feat has never been repeated since. The Piccards are surprised to discover life dwelling at this depth. Shortly afterward, the world's attention shifts to space exploration, and funding for deep ocean exploration wanes. Bryson says it's strange that we know more about the surface of the moon than the ocean floor—humans have only examined a "billionth" of the ocean's dark depths.

Beebe, Barton, and the Piccards' underwater adventures all show, once again, that scientific speculations about environments that humans haven't traversed are often wrong, meaning that there is a lot of scientific work to do. Humans have only descended the Mariana Trench once and have only explored an infinitesimal fraction of the deep ocean, which shows how little progress scientists have made in this area. Thus, scientific discovery of the oceans is only at its beginning.

Nevertheless, explorers have still yielded some curious insights, leveraging a United States Navy's deep-ocean exploration device called "Alvin." In 1977, oceanographers discover 10-foot-long tube worms, giant clams, and bacteria living around deep-sea vents in the Galapagos. Shockingly, this ecosystem survives using "chemosynthesis" instead of photosynthesis, deriving energy from hydrogen sulfides instead of sunlight. This was previously thought to be impossible as hydrogen sulfides are toxic to all other known living creatures. Oceanographers also learn that sea organisms can survive at much colder and hotter temperatures than they thought was possible for any life forms, radically revising biologists' understanding of the conditions necessary for life.

As with other realms of discovery, what becomes immediately apparent when deep ocean exploration takes off is that the more humans witness in the world, the more we realize how little we know and how fallible our scientific claims are. This is evidenced by the presence of creatures that can survive by means that were previously thought impossible. The presence of such creatures also shows that life is really a wondrous thing, since it somehow exists in the strangest and harshest environments and in very diverse ways.

When water evaporates, it leaves salt behind, so it would seem that the oceans should get saltier over time—but they don't. Geophysicists realize that the ocean's deep-sea vents act like filters: they strip out salt from water and blow clean water back out, maintaining equilibrium in the oceans. Sadly, Bryson says, most research in the 1950s focused on discovering spots in the ocean to dump radioactive waste. Between 1950 and 1999, The United States alone dumps hundreds of thousands of drums leaking plutonium, uranium, and strontium into the ocean—as do most European nations, Russia, China, Japan, and New Zealand. Scientists still have no idea what long-term effects radioactive pollution will have on the oceans and Earth's overall ecosystem.

Bryson utilizes the example of ocean pollution to show, once again, that humans are frequently reckless with the environments we live in—this time, our oceans, which we pollute with toxic waste. This recklessness is foolish because we know so little about how our actions could impact our ability to sustain life on Earth. Humans, thus, are a tremendous threat to our own existence because we fail to acknowledge the delicate interrelatedness of everything on Earth, and we frequently disrupt the planet's equilibrium.

Humans know shockingly little about marine life. For instance, we still have no idea where blue wales mate or why they sing. Some scientists estimate that there could be over 30 million species of sea life in the oceans, "most still undiscovered." Sea life clusters around shallow waters, and most ocean space is uninhabited—perhaps even uninhabitable. Coral reefs comprise one percent of the ocean's space, yet they're home to 25 percent of the world's fish species. Bryson wonders why humans tax the oceans by overfishing shallow waters. Some shark species, as well as cod in particular, are teetering on the brink of extinction from overfishing. We still overfish despite this, yet we barely know anything about the long-term effects of our actions on the oceans' ecosystems.

In addition to polluting oceans with toxic chemicals, humans also tax the oceans with overfishing. Bryson stresses that the oceans are deceptively large, as the vast majority of life exists in shallow fishing waters. In this way, humans aren't only a threat to our own existence—we also frequently drive other species to extinction without a second thought. This behavior is reckless because such effects could trickle up the food chain and dramatically affect the ability of many other species (including our own) to survive.

CHAPTER 19: THE RISE OF LIFE

In 1953, graduate student Stanley Miller connects two flasks with tubes: one contains water, and the other contains methane, ammonia, and hydrogen sulphide gases (to represent Earth's early atmosphere). When he adds electrical sparks to the mix (representing lightning), a "hearty broth" of amino acids and other organic compounds emerge. Scientists think that life originated this way on Earth. Unfortunately, progress into the origins of life hasn't developed much further since then. Subsequent experiments using nitrogen and carbon dioxide—which were more likely abundant in Earth's early life—yield only one primitive amino acid.

Bryson addresses Miller's experiment to show that another area of human knowledge that the origins of life on Earth is another area of knowledge that's highly speculative. The furthest humans have gotten to understanding how life gets going at all is one experiment that shows organic compounds emerge in a certain atmospheric environment—but this environment isn't necessarily the one that Earth sustained. Yet again, this part of our origin story evades scientists—it remains all but shrouded in mystery.

Amino acids—"the building blocks of life"—join together to make proteins. It takes 1,055 amino acids joined in a specific order to make collagen, for example. It's hard enough to do this on purpose, but the fact that it happens "spontaneously, without direction" is astounding. Additionally, "perhaps a million" different proteins are created this way, and the statistical odds of this happening effectively fall to zero. After proteins are created, they need to be reproduced, but only DNA can do this—and DNA and proteins also need a protective membrane around them (a cell) to function. All of these components have to come along at just the right time for life to arise. Bryson says that life really does seem to be a "miracle."

Bryson stresses that the way that organic life appears to arise, as well as the fact that it did so on Earth, is nothing short of amazing. Humans often take the possibility of life for granted, but the fact that life is likely the result of spontaneous accidents involving molecules bumping into one another in just the right way at just the right intervals is astounding—the chances of life evolving at all *are so rare that rather miraculous that it actually did happen. This phenomenon thus commands our awe.*

Bryson thinks the best explanation for this "miracle" is evolution. Creationists (like Hoyle) essentially argue that all the proteins needed for life come into the world fully formed at once. Richard Dawkins (author of *The Blind Watchmaker*) argues that they develop over time, through trial and error of proteins bumping into each other and latching on in many different ways. Nature does seem to have an impulse toward "ordered self-assembly"—complex patterns are everywhere. Take crystals, or snowflakes, for example. Living organisms—from lettuce to human beings—are made of simple components: carbon, hydrogen, oxygen, nitrogen, sulfur, phosphorus, calcium, and iron. If these elements are combined in about 36 different combinations, an organism can be formed.

Bryson alludes once again to the ways that religious intuitions can misdirect scientific thinking, since a great many scientists (including Hoyle) persist in maintaining that life is created all at once by a creator, despite how unlikely it is that such a phenomenon occurs at such. The evidence, in fact, points much more strongly to evolution, which only becomes scientifically legitimatized in the late 19th century, showing how religious values slow scientific progress when scientists try to marry their beliefs with the empirical evidence on Earth.

Factoring in Earth's age—and the fact that Earth's crust didn't form until 3.9 million years ago—it means that life has to go from bacteria to human beings in approximately 3.5 billion years, which is surprisingly short for that degree of evolution. This is why some scientists—including the great Lord Kelvin—think that life had some help from space. Surely enough, in 1969, a 4.5-billion-year-old meteor explodes over Australia, and its chunks are "studded" with amino acids. Another asteroid that lands in Canada in 2000 also contains organic compounds.

Even when the evidence pointing to life's origins on Earth is considered, there's still a great deal that scientists don't know—it might even be that the first organic compounds came from space, since there is some evidence to support this. This sort of speculation shows how little scientists actually know about the conditions that gave rise to our existence.

However, Bryson thinks that "panspermia" (the theory that life got going with the help of some extra-terrestrial organic compounds from asteroids) is problematic, because it doesn't explain *how* organisms evolve out of compounds, and it can encourage crackpot theories about "aliens." Hoyle, for example, argues that panspermia brought the flu and the bubonic plague to Earth from space, and that human nostrils evolved facing the ground so that pathogens raining on Earth from above wouldn't go up our noses. Bryson says that however life got started, we know that all life on Earth came from a single "primordial twitch." Some chemicals somehow managed to spark into life and to produce an "heir" from part of itself. Biologists call this the "Big Birth."

Bryson thinks that appealing to organic compounds from space is a bit of a cop-out, since it still doesn't solve the mystery of how life gets going. Thus, even with the evidence scientists do *have, there is much that remains to be explained, and therefore a lot of scientific work still to do. That being said, the fact that life did happen—even though we still don't know how—is still miraculous, since it seems (as far as we know) that all life originates from a single "primordial twitch" that could have just as easily never happened.*

A geochemist named Victoria Bennett, who's trying to map Earth's landscape 3.5 billion years ago (when life got started) explains to Bryson that if a scientist pulverizes ancient rock, it's possible to detect chemical residues that life leaves behind (such as carbon isotopes). Bennett does this using a machine that also ages rocks by measuring the decay of uranium into zircon minerals. Her research shows that all in all, early Earth doesn't seem conducive to life, especially before an atmosphere forms—yet there are still traces of organic life from that time. Bennet concludes that something must have suited life in those harsh early conditions, "otherwise we wouldn't be here."

Bryson stresses that the "primordial twitch" that began life is even more miraculous than it already seems, because as scientists like Bennett begin to learn more about the young Earth's early geological and atmospheric environment, they realize that it's largely inhospitable to organic life. Yet somehow, life did get going, which further underscores how much wonder and awe life commands for having happened at all.

Bennett explains that Earth's early atmosphere is noxious, sulfuric, and only has trace amounts of oxygen, much like Mars's current atmosphere. For two billion years, there's just bacteria. At some point, "cyanobacteria" (blue-green algae) starts absorbing water—consuming water's hydrogen and releasing oxygen as waste—thereby inventing photosynthesis. The process makes algae sticky, so clumps of dust stick to it, creating "stromatolites." Stromatolites are living rocks made of cyanobacteria, dust, and sand. In 1961, scientists even discover a small colony of living stromatolites in Australia, which expel little bubbles of oxygen as they consume water. When stromatolites rise out of the water, they expel oxygen into the atmosphere instead of into water.

Bennett's evidence points to how inhospitable early Earth's environment is to oxygen-dependent beings, because the early atmosphere is largely absent of oxygen. This means that before oxygen-dependent life forms can form, organic life has to form that doesn't rely on oxygen but somehow pumps the atmosphere full of it. Thus, our evolution depends not only on life beginning, but beginning in such a way that it facilitates an oxygen-rich atmosphere, rendering the history of our existence even more astounding.

Two billion years later, there's enough oxygen in Earth's atmosphere for mitochondria to evolve. They consume oxygen and facilitate respiration in cells. Eventually, life evolves into an equilibrium between organisms that expel oxygen (like plants) and organisms that consume oxygen. These oxygen-consuming organisms exist first as single-celled organisms called "protozoa," and then, after another billion years, as multicellular organisms, which evolve to be increasingly complex, eventually giving rise to humans.

Bryson emphasizes the almost inconceivably long time it takes for both life, and the environment that life thrives in, to evolve from sustaining simple organic compounds to sustaining fully-fledged human beings. The sheer scale of this history implies there are vast stretches of geological and biological time about which scientists know very little.

CHAPTER 20: SMALL WORLD

There's no point hiding from bacteria because they're perpetually "on and around you": healthy people have about a trillion bacteria living on their skin alone that eat dead skin, oils, and minerals from our bodies. There are trillions more in our gut and nasal passages, on our eyes, and in our teeth. We think antibiotics and disinfectants have all but rid the world of bacteria, but Bryson says that in actuality, Earth is the bacteria's planet—they were here before us, and they'll be here long after us. We're alive because of bacteria, which perform all the necessary functions to keep us and Earth running—including converting nitrogen into amino acids, making waste rot, converting food into sugars, and keeping our atmosphere oxygenated.

Bryson highlights how much humans depend upon bacteria to survive in order to dispel the popular notion that bacteria are bad because they cause diseases. In fact, bacteria keep both Earth and our bodies in equilibrium—they sustain our environment and ourselves.

Bacteria reproduce much more quickly than humans—in a matter of minutes. When bacteria reproduce, about one in a million of their offspring is a mutant. Usually, mutants don't survive, but sometimes the mutant has an accidental advantage such as the ability to resist antibiotics. Bacteria share these advantages easily and rapidly because they share a single gene pool. All they need to survive is moisture—and they're everywhere, from the bottom of the Mariana Trench to deep inside Earth's interior. Some are even immune to radioactivity. Bryson says that they're practically indestructible. In 2000, an American scientist named Russell Vreeland even resuscitates 250-million-year-old bacteria trapped in ancient salt deposits.

Despite the fact that bacteria are so essential to life, scientists are perpetually surprised by how limited their knowledge of bacteria is. Bacteria appear to survive in many environments that scientists assume are impossible for sustaining life until they realize otherwise (such as deep inside Earth's interior). At the same time, the sheer hardiness of bacteria show that life, somehow, finds a way to exist in the harshest of environments, further demonstrating how extraordinary life is and how much wonder it invokes.

Most textbooks divide the world into plants and animals, but they barely mention bacteria. In the late 19th century, German naturalist Ernst Haeckel suggests that bacteria need to be included as a third category of organism, but it takes until the 1960s for biologists to embrace the idea. The plant versus animal division also doesn't suit organisms like fungi, mildews, and yeasts, as they are considered plants but have more in common with animals because they don't use photosynthesis, but they consume the plant or rock that they grow on. Slime molds also coalesce into slugs that can crawl to another location before reverting back to something more like a plant form.

Bryson stresses life's biodiversity in order to emphasize the importance of systematizing it in digestible ways. At first, efforts to draw up categories of organism exclude bacteria—which is problematic considering how abundant they are—and they fail to adequately account for fungi, mildew, and molds. Our scientific understanding of life's biodiversity is thus dependent on our ability to come up with a clear framework for categorizing it.

In 1969, an ecologist named R. H. Whittaker proposes dividing life into not two, but five branches or "kingdoms": animals, plants, fungi, monera (bacteria) and protista (meaning everything else). Many biologists, however, dislike the vagueness of the "protista" kingdom, which functions as a sort of vague catch-all for things they can't classify well, like slime molds. Carl Woese subsequently studies bacteria genes and argues that bacteria are actually several different types of unrelated organisms. In 1976, he redraws the tree of life with not five, but 23 categories, but his efforts are largely ignored for focusing too much on the microbial world, which botanists and zoologists deem irrelevant.

Bryson shows how difficult it is to categorize life's biodiversity accurately and how often there is a need for catch-all categories for things that don't fit the system (like slime molds). As such, he stresses how dependent scientific progress is on good, clear, categorizations. The scientific endeavor in this area depends just as much on systematizing organisms well—specifically in useful and functional ways that help biologists make sense of the world around them—as it does on discovering organisms.

Nonetheless, Bryson thinks that Woese's system shows us how incredibly diverse life is, and how most of the diversity happens at the "small, unicellular, and unfamiliar" level. This means that complex organisms, like humans, are essentially "side branches" of the real story. Creatures that we can see with the naked eye are only three of 23 categories, and 80 percent of the total biomass of all living things is made up of microbes.

Bryson thinks that humans often over-inflate our sense of importance in the world because we overlook microorganisms that we can't easily see. In fact, we are just a side-plot to the central story which centers on bacteria. This implies that our existence is even more rare and lucky because it's a minor occurrence in the picture of how life typically thrives.

Most illness symptoms don't come from microbes, but from our immune systems. In an effort to kill the invading microbes, our immune systems also damage some of our own tissues, making us unwell. The body also diverts energy toward making extra white blood cells, which are needed to attack invading bacteria. Some bacteria also inadvertently cause damage when they wander into the wrong part of the body. For instance, one type of bacteria normally causes strep throat—but if it gets past the throat's lining, it become completely resistant to antibiotics and consumes the body from inside out. Bryson thinks that we'd handle bacteria much better if we didn't flood the world with antibiotics so often, which causes bacteria to evolve resistance to antibiotics.

Bryson revisits the issue of how carelessly humans endanger our own existence with antibiotics. Antibiotics serve a purpose because they can kill bacteria that is deadly. However, overuse of antibiotics enables bacteria to evolve a resistance to it. The more abundant a phenomenon is in an environment, the more life in that environment evolves to tolerate it. Microbial warfare can thus have catastrophic effects to our livelihood that humans ourselves cause.

In the early 1960s, William Stewart, the United States Surgeon General claims that humans can "close the book" on infectious diseases because penicillin has become fully effective against all strains of staphylococcus bacteria. But unbeknownst to him, around the same time, 90 percent of those strains begin developing an immunity to penicillin. In fact, humans haven't developed a new antibiotic since the 1970s. Even more alarmingly, in 1983, an Australian doctor named Barry Marshall discovers that deadly stomach ulcers and many stomach cancers are bacterial in origin. It takes over a decade for his suggestion to become scientifically accepted. Bryson thinks that it won't be long before we lack an effective antibiotic for any bacteria because of our "carelessness" in overusing antibiotics.

Yet again, Bryson points out a case in which a scientist (this time, the Surgeon General) proclaims that humans have conquered an area of scientific knowledge (here, infections disease), while the opposite is, in fact, true. Bryson stresses that life on Earth is highly adaptable, meaning that whenever humans think we've mastered a scientific phenomenon, we're typically wrong because the environment we've mastered will inevitably change. When—not if, but when—bacteria evolve to survive antibiotics, scientists will know nothing at all about how to combat many infectious diseases. Once again, this problematic outcome is one that humans accelerate through our "carelessness."

Bacteria can also get sick when they're invaded by viruses called "phages." Viruses aren't alive, but they burst into life when they find a host and hijack the genetic materials of living cells to reproduce. Viruses account for many diseases, including smallpox, rabies, and HIV. Viruses can also become active and then mysteriously vanish, or lie dormant before suddenly surfacing. The Spanish Flu pandemic of 1918 (which likely killed up to 100 million people) arose as multiple simultaneous outbreaks around the globe, far more quickly than people could travel back then. It triggered a worldwide pandemic in under a week, meaning it wasn't spread person-to-person but must have been already present worldwide and somehow activated, though it's unclear how.

Even in the current world—whereby humans are able to allay some of the threats to our survival with antibiotics—there are severe limitations to our knowledge of deadly viruses. Scientists can neither cure viruses nor explain the mechanism that activates them from a dormant to a deadly state. All this shows that humans are extremely lucky to still be here, since we could easily be wiped out by a common—and deadly—phenomenon that we can barely understand, let alone defend ourselves against.

New, deadly viruses crop up all the time and often spread in inexplicable ways. For instance, in 1969, a doctor who was studying Lassa Fever microbes in a Yale University lab came down with the disease and survived, while a lab technician who had no direct exposure also contracted the disease and died. Bryson notes that today's globalized culture of air travel "invite[s] epidemics"—humans may not be so lucky the next time we have a pandemic on our hands.

Bryson draws on the case of Lassa Fever to show that even though humans assume viruses spread from person to person by close contact, there are still viruses that appear to spread in ways that we cannot yet understand. This further highlights how limited our scientific knowledge is and how much work there is to do. The limitations in scientific knowledge of diseases paired with the increased likelihood of their spread in a globalized world show just how precarious the survival of our species is.

CHAPTER 21: LIFE GOES ON

Most organisms—over 99.9 percent—decompose without a trace. From the remaining 0.1 percent, some will become fossilized, but only if the organism is buried in sediment without exposure to oxygen. If it's left undisturbed for long enough, the organism's bones can make an imprint on the sediment as it decomposes, which can become filled in by minerals as the rock is compressed over time. Fossils are extremely rare: Bryson estimates that only one in a billion bones ends up fossilized. Moreover, most land animals don't die in sediments. In fact, 95 percent of fossils that humans have collected are from marine life that died in shallow seas. Our fossil records thus represent only the "merest sampling of all the life that Earth has spawned."

Most of what scientists know about ancient life on Earth comes from fossils. The rarity of fossils—and particularly the extreme rarity of land-based fossils—shows that scientists have a severely limited and highly fragmented picture of Earth's ancient species. Bryson emphasizes this to stress, once again, how little scientist know about the world around them (this time, ancient life), and how much knowledge about life in Earth's history may inevitably evade us. Thus, there will always be a demand for scientists who to want narrow the gap between what we know and what we can never grasp about the past.

Bryson meets paleontologist Richard Fortey at the Natural History Museum in London, where Fortey shows Bryson a display of ancient "trilobite" fossils. Very little is known about these small marine animals except that they're the earliest complex life forms we know of, they flourished suddenly during the "Cambrian explosion" 540 million years ago, and they vanished in a mysterious mass extinction 300,000 years later. Humans have only existed for 0.5 percent of that time. Little is known about early Earth's evolutionary history until a paleontologist named Charles Doolittle Walcott discovers the "holy grail" of fossils.

While the sparsity of fossil evidence is a serious hindrance to scientific knowledge, scientists still struggle when evidence does surface—such as Walcott's extraordinarily rare find of fossils from the Cambrian explosion—since there is still a wide margin for error in making sense of new evidence as it is discovered. Bryson further stresses that even with an abundance of evidence, there is a lot that scientists need to figure out.

During a trip in the Canadian Rockies in 1909, Walcott hikes up to the top of a hill and discovers a perfectly preserved 500-million-year-old fossil pit, now known as the "Burgess Shale." It contains over 60,000 specimens from the Cambrian explosion. Sadly, the Burgess Shale goes largely unnoticed for over 70 years because Walcott under-describes the specimens as primitive ancient worm fossils in his writing. However, in 1973, graduate student Simon Conway Morris visits the Burgess fossils and is astounded to discover they are "far more varied and magnificent" than Walcott described.

Bryson raises another example of how uninspiring descriptions of scientific evidence hinder scientific progress. Walcott's underwhelming descriptions of his find mean that scientists fail to fully address them for decades. Morris's eventual analysis of the Burgess fossils once again shows that the more evidence scientists uncover, the more they are surprised by what they see.

Morris starts cataloguing the collection and discovers that these animals are unlike any others known to humankind—one species had five eyes and claws at the end of a long snout. Another scientist named Stephen Jay Gould suggests that the Cambrian explosion might have been a sort of "trial and error" experimentation period for early "body design." Controversially, some scientists take Gould's claim as evidence of creationism, believing that they've captured a maker experimenting with fully-formed life-forms before evolution proper kicked off.

The sheer strangeness of the Burgess fossils prompts speculation about what they mean. Bryson shows again that religious beliefs often intercept scientific progress. Here, religious biases prompt scientists to make problematically wild leaps that extend beyond the evidence in order to justify creationism.

However, a British paleontologist named John Mason soon identifies a flatworm fossil specimen that predates the Cambrian explosion by 100 million years. Evolutionary theorist Dawkins argues that the flatworm fossil shows that the Burgess fossils evolved from earlier, simpler Precambrian life forms, thus proving that evolution (and not God) is responsible for them. Dawkins also argues that many of the Burgess fossils were assembled incorrectly, making them look stranger than they actually are. Bryson concludes that we may never solve the riddle of the Burgess fossils, since our entire knowledge of Precambrian life resides in a single fossilized fish specimen and we have no information about the gap between.

Bryson implies that the impetus among many scientists to confirm their religious biases can cause them to be hasty in making sense of new evidence. The Burgess fossils, for example, are assumed to be radically different than they actually are because many of them are assembled incorrectly. The incorrect assembly also shows how fallible and prone to error scientific claims are, while the relative lack of evidence means that insights into Earth's early life forms remain a mystery that scientists have yet to solve.

CHAPTER 22: GOODBYE TO ALL THAT

Humans want to think we have a purpose on Earth, but science shows us that sometimes life "just is." Lichens, for example, live out their existence by simply clinging to rocks, absorbing minerals for food. If Earth's history were compressed into a single day, life would get going at four a.m. with microbes. It takes until 8:30 p.m. for sea plants and jellyfish to show up. Around 10 p.m., land plants emerge, and around 11 p.m., the dinosaurs turn up, lingering until 11:40 p.m. Humans show up at 11:59 p.m., and they've so far been on the scene for just one minute. Bryson suggests that perhaps most life isn't ambitious because complex organisms tend to go extinct, while simpler ones—like jellyfish—are still around.

Bryson invokes the analogy of life as a single day on Earth to show how late into the day humans come onto the scene and how short in duration our time on this planet has been thus far. Nearly all of Earth's history—everything up to the last minute of the day—happens before humans exist, meaning that there is a near-infinite amount of scientific information yet to be gleaned about the past. The metaphor also emphasizes the rarity of human existence: our species is a tiny blip on the timeline of Earth's history, meaning that most life doesn't evolve into human life.

In order for marine animals to evolve into land life, creatures have to develop a different internal architecture (including a load-bearing spine) and learn how to consume oxygen from the air instead of water, which is no easy feat. Though we usually imagine our ancestors as fish with legs, or as early amphibians, they're most likely mites (living on plants) that crawl onto land when plants do. Dead vegetation falls into swampy sediment instead of fully decomposing and releasing carbon dioxide into the air, resulting in much higher oxygen levels that enable land life to rapidly grow larger. Early millipede fossils reveal specimens as large as six feet long.

Bryson wants to stress that the fact that human life evolved at all is astounding, since it required marine life to evolve into land life—which demands a complete restructuring of both the skeleton and respiratory systems. Bryson further emphasizes the marvel of life in general by stressing how much larger everything was when there was more oxygen on Earth. Bryson helps the reader to visualize this so that they can become both fascinated and amazed about the planet we live on.

Eventually, insects evolve to fly. Early dragonflies are as large as ravens, and plant life is much larger too—ferns alone rise 50 feet high. In 1948, an eccentric Swedish scientist named Erik Jarvik acquires an "Ichthyostega" fossil, which scientists think might be the common ancestor fish for all tetrapods (a category that includes dinosaurs, whales, birds, humans, and fish). Unfortunately, Jarvik locks it away in his office and it doesn't surface again until after his death in 1998, when scientists realize Jarvik that mis-described it—it's not, in fact, a tetrapod. Since then, no other viable early tetrapod fossils have been found, so this part of our history remains a mystery.

Bryson shows that despite all the obstacles to scientific knowledge about historical life on Earth that humans face—such as a paucity of evidence—the eccentric personalities of scientists themselves can also slow down scientific discovery, as the case of Jarvik shows. It takes almost 50 years for scientists to realize that his fossil isn't the one they're looking for. The complete absence of fossils from crucial periods in the history of life shows that most of the story of evolution still evades scientists.

Scientists divide land-creature evolution into four "megadynasties." The first consisted of primitive reptiles, amphibians, and turtles. One branch of these creatures evolves into the earliest "protomammals" (called therapsids) who comprise the second megadynasty. Meanwhile, another branch evolves into dinosaurs, who destroy nearly all the therapsids except for small burrowing mammals about the size of mice. The dinosaurs take over and comprise the third megadynasty, followed by our own "Age of Mammals." Bryson says one of the strangest features of life is the prevalence of extinction. Over 99.99 percent of all species that have ever existed have gone extinct. The typical life span for complex species before extinction is about four million years, which is about where humans are right now.

Even though the idea of human extinction seems remote to us on a day-to-day basis, it's actually not—in fact, it's likely inevitable. Bryson cites the fact that 99.99 percent of species go extinct in order to show the reader how precarious human existence is. In fact, it's even more precarious today than it's ever been before, because most species go extinct after they've been around for about as long as humans have been around now. Bryson's aim is to show that extinction is already the likely outcome for our species, so we should not accelerate it by being reckless with human life.

Though it seems counterintuitive, extinctions are actually good for life's evolution—mass extinctions are typically associated with massive leaps forward. For example, darting fish only began to thrive after immobile filter feeders went extinct. Earth has had five mass extinctions in its history (all before the era of dinosaurs), each of which wiped out approximately 70-95 percent of Earth's species. There were also 12 or so smaller-scale extinction periods, though one of them almost wiped out horses. (Bryson can't imagine the world without horses.) Figuring out *why* mass extinctions happen, however, is much more difficult. Scientists speculate that anything from climate change to "catastrophic" solar flares might be responsible for Earth's mass extinctions.

Mass extinctions provide important clues about evolutionary processes, since they typically drive evolution forward. Despite how important it is to know about prior extinctions in Earth's history, scientists actually know very little about them—they know that they happened, but they don't know why. *Five of these extinctions have been mass extinctions that wipe out most life on Earth, further stressing how perilous the continued existence of our species is. The fact that we've lasted so long is very lucky, especially as we have insufficient knowledge about what triggers mass extinctions in the first place.*

Bryson explains that the KT asteroid impact that wipes out the dinosaurs is enormous. The impact's force exceeds the power of eight billion atom bombs. The KT impact also happens when Earth is more oxygenated—and therefore more combustible. The asteroid lands in a shallow sea bed made of sulfur, triggering several months of burning acid rain, while debris from the impact blocks out the sun for months, maybe years. Yet curiously, 30 percent of species survive this event, including crocodiles, snakes, turtles, amphibians, and corals. It turns out that the impact kills 90 percent of land animals (including all the large ones) but only 10 percent of sea animals (sparing large sea creatures like sharks).

Though Bryson, thus far, has warned about the dangers of asteroid impacts and emphasized how closely humans come to total annihilation on a daily basis, our existence—paradoxically—also depends upon asteroid impacts. If the KT impact didn't happen when mammals were very small and dinosaurs were very big, humans likely wouldn't have evolved at all. Once again, Bryson stresses that our existence is a matter of sheer luck.

Luckily for humans, the land survivors include our ancestors: tiny, nocturnal, burrowing mammals. With the dinosaurs gone, mammals thrive. Bryson says this historical age sees guinea pigs as large as rhinos, rhinos as large as two-story buildings, and fierce 10-foot-tall carnivorous birds. Unfortunately, too few fossils have been discovered thus far for scientists to paint an accurate picture of the early age of mammals. Similarly, the 300 or so dinosaur fossils discovered in the 19th and 20th centuries capture just a mere glimpse of life in that age. Bryson says that humans feel sure about our status as life's "dominant species," but actually, "we are here only because of timely extraterrestrial bangs, and other random flukes."

Bryson employs colorful descriptions of giant mammals in our ancestral line to peak the reader's interest and inspire their imagination, reflecting the kind of writing that he thinks will fuel scientific engagement among the general populace. This is particularly pertinent for discussions about the early age of mammals since scientists have little to no evidence about life during this time. Even the discovery of one new fossil would therefore be game-changing for the scientific community. Bryson closes out the chapter by stressing once again that the existence of our species is dependent upon the whims of chance.

CHAPTER 23: THE RICHNESS OF BEING

London's Natural History Museum is full of back corridors where scholars study samples—the museum contains over 15 miles of jars and folders containing everything from mollusk shells to pressed plants. Some scientists spend years studying one plant alone. Bryson enters the botany department and meets Len Ellis, who works as a curator of "bryophytes," or mosses. There are 10,000 known moss varieties, though in the tropics more species are found each day. In fact, Ellis says that he has "no idea" how many species of moss live on Earth, though he thinks there are many more than the ones scientists have already discovered.

Bryson shifts to discussing Earth's current biodiversity in order to stress that even when it comes to getting a full scientific grasp of the life that's currently on Earth—even land life, which humans have the closes access to—scientists are limited in the knowledge they've gathered so far. The number of plant species alone that exist is so vast that scientific discovery has an extremely long way to go in identifying them.

It takes about six months to catalog a new moss once it's been discovered, and these species often disclose new mysteries. The London Natural History Museum has 780,000 moss samples so far, including 30,000 plant specimens from famous British botanist Sir Joseph Banks, who sailed to Australia with Captain Cook during the famed 1769 transit of Venus. In 18th-century Europe, plant collecting is a popular and lucrative recreational pastime, with new varietals earning handsome sums on the commercial market. To Bryson, the "volume of life on Earth" is "seemingly infinite."

Bryson discusses mosses in particular to stress that scientists even lack an adequate picture of life on Earth when it comes to one sub-species of plant life. The "seemingly infinite" diversity of plant life on Earth shows that scientists' work may never be done—especially as new species continue to evolve.

The sheer volume of species in the world (including plants and animals) demands a good classification system, or "taxonomy." One such system is devised in the 1700s by eccentric Swedish botanist Carle Linné, who names weeds after people he doesn't like. Linné dramatically simplifies existing species names, which are highly disorganized in his time. Linne is the first person to classify whales as mammals based on similarities in their respiratory systems. Today, nearly all of his names are still in use (with the exception of sexually vulgar ones, which he has a curious fondness for). Linné divides animals into six categories—mammal, reptile, bird, fish, insect, and worm—though it takes until 1902 for naming systems to be standardized on an international level.

Bryson has stressed that functional descriptions and systems are essential for scientific progress when it comes to physical, chemical, and geological phenomena. Now, he stresses the importance of this activity for biological organisms. Bryson thus adds further weight to his claim about the necessity of good descriptions for the scientific endeavor. Linné's contributions make some progress in this regard, but even his system can be improved upon, meaning that there is still a lot of work to do.

Taxonomy is fraught with duplications, however, because many species look very similar. Scientists also often disagree on how new species should be classified. The renaming of "chrysanthemum" flowers to "dendranthema" (for consistency purposes) in the 1980s is met with such uproar that the International Association for Plant Taxonomy has to change the plant's name back to "chrysanthemum" in 1990. Frequent disputes and reclassifications mean that "we don't have the faintest idea" as to how many species of life there actually are on Earth—estimates range from "3 million to 200 million." Moreover, scientists think they've only discovered three percent of Earth's species. There are also disagreements within sub-categories: for example, some scientists think that there are 4,000 species of earthworm, while others think that there are 12,000.

Bryson stresses that when it comes to life on Earth, the task of generating clear and adequate descriptions is even harder, partly because of the sheer volume of species and partly because of how inconsistent classification systems have been in the past. There is thus a pressing need for good, clear classifications of biological life to help science in this area progress. The volume of life's species provides further evidence that scientific knowledge about current life on Earth is highly limited, and it still has a long way to go.

Estimates vary so much because it's difficult to extrapolate from a sample to the world at large, and taxonomists often struggle to decipher 19th-century classifications when checking for duplications in historical publications. Bryson thinks we know "as little as we do" because of four reasons. First, most living things are very small. A typical mattress is home to 2 million microscopic mites, for example, though mites weren't discovered until 1965. Bryson urges the reader to image how many equally small species exist in undiscovered parts of nature.

Another reason why scientific knowledge of current life on Earth is so limited is because most life is microscopic. This means that there is a lot of area to cover, implying that the scientific endeavor to catalog Earth's life forms is going to take a very long time. It's even difficult to know when a new species is discovered because historical classifications are often unclear. This further shows how unclear writing or systematizing can hinder scientific progress.

Second, scientists often don't look in the right places. Historical searches focusing on Europe and North America, for example, overlook rainforests, in which over half of animal life and over two-thirds of plant life live. At least 99 percent of flowering rainforest plants have never been tested for their medicinal properties (since plants can't flee predators, they often have inbuilt chemical defenses with profound medicinal potential). Third, there aren't enough specialists. Fungi, for example, don't entice many researchers, meaning that only 70,000 of a potential 1.8 million species have been cataloged so far.

Bryson argues that scientific knowledge is also in its infancy when it comes to Earth's life forms because many environments where the greatest biodiversity exists are underexplored, such as the planet's rainforests. Scientific discovery also demands a lot of specialized human labor—far more than is presently available. Once again, Bryson emphasizes that scientists aren't even close to learning all there is to know about life on Earth.

Finally, the world is huge—air travel and communication are deceptive compared to how much literal ground there is to cover. The flightless "tahake" bird of New Zealand was pronounced extinct 200 years ago, but it was recently rediscovered alive and well in a remote rugged area of the island. Discovering all life would demand upturning every single rock on Earth. New species are also often discovered living in places assumed to be inhospitable to life (such as blind, colorless insects that live deep underground). It would demand an array of specialists waiting to analyze all these curious species, all willing to devote decades to one varietal alone, and there simply aren't enough people interested in doing that.

Bryson argues that scientific discovery of current life on Earth is only just getting started because there's so much ground to cover. Even species that scientists believe went extinct crop up alive and well as scientists make more headway in exploring Earth's land surfaces. Humans may think we've conquered the globe, but this belief is deceptive—it will likely take scientists countless years to cover all the ground they need to, meaning that the majority of the scientific journey lies ahead of us.

CHAPTER 24: CELLS

Bryson says that cells are a "thing of wonder"— even the simplest are "far beyond the limits of human ingenuity." When a cell divides, each new cell contains complete copies of the instructions needed to do everything in the body. It takes 47 cell divisions to create the 10,000 trillion cells needed to make a human. Even a simple yeast cell contains the same number of components as it takes to build a Boeing 777 airplane, and yeast cells are "nothing compared with human cells." Human cells do everything from making hair grow, metabolizing food, and allowing people to form thoughts their minds.

Bryson discusses life at the cellular level to emphasize how incomprehensibly complex and wondrous life is. For Bryson, the level of activity and complexity of cellular life is astounding, and he wants the reader to feel this too. He hopes to foster a sense of amazement about everything it takes to keep life going—and therefore a greater sense of appreciation for life itself.

We understand "little of how cells do the things they do." Some scientists even argue that we only have a competent grasp of two percent of human cells. There are several hundred types of human cell, ranging from nerve cells containing several feet of curled-up filaments to rod-shaped photocells that enable vision. The average human cell is 20 microns wide (0.02 millimeters) and most last for about a month before being replaced—except liver cells, which last for years, and brain cells, which last for the entire lifespan (though their components are frequently renewed). In fact, a person's cellular components are completely replaced every nine years (meaning that on the cellular level, a person is never more than nine years old).

Despite the fact that cellular life is so important when it comes to making sense of human life, scientists know astoundingly little about it. Again, Bryson emphasizes that just like every other aspect of the scientific endeavor that he's discussed so far, scientific knowledge of cells is highly limited. Scientists have only learned a fraction of everything there is to know about life at the cellular level, meaning that as with everything he's discussed so far, scientists still have a long way to go.

Robert Hooke first describes (and names) the "cell" in 1665. Microscopes of the time can only magnify the world about 30 times. Curiously, an uneducated Dutch linen draper named Antoni van Leeuwenhoek invents one that can magnify things 275 times, but he keeps his instruments secret and only shares drawings of his observations. Leeuwenhoek's drawings prompt a craze among scientists. Fellow Dutchman and respected scientist Nicolaus Hartsoecker is even convinced he can see "tiny preformed men" in sperm cells, and he claims that humans are giant blow-up versions of miniature cellular selves. It takes scientists until 1839 to realize that *all* living matter is cellular, and until the 1860s for famed scientist Louis Pasteur to conclude that life cannot arise without cells, laying the foundations for modern biology.

The task of scientific discovery is so vast when it comes to cellular life because cells are so small, meaning that human understanding of cells is dependent upon the development of adequate technology to examine them, and this doesn't happen until the 19th century. Bryson leverages the example of Hartsoecker to show how humorous erroneous scientific claims about newly discovered phenomena can be. Bryson's example also subtly alludes to his claim that patriarchal values often unfairly privilege male scientists—the sheer absurdity of some of their claims shows that they don't necessarily have a better grasp on science in virtue of being men.

To Bryson, a cell is a "nightmarish place" somewhere between a city and a factory with ceaseless activity, electrical energy, and no gravity (this force doesn't have a feasible impact at the microscopic scale). Cells combine the food and oxygen we consume to generate electricity. If one imagines that atoms were pea-sized, a cell would be half a mile wide, and its outer membrane (which is made of fat) would seem as rigid as iron. The cell would contain millions of objects ranging between the size of a baseball and the size of a car, moving as fast as bullets.

Bryson symbolizes life inside a cell as a "nightmarish place" that is unimaginably chaotic. His symbolism helps the reader to visualize life at this scale by enabling them to imagine themselves inside a cell. Bryson intends to foster engagement with science by fueling the imagination, which he argues is much more effective than simply citing abstract claims.

At this scale, it would be impossible to stand in a cell without being torn to shreds. Each strand of DNA is damaged every 8.4 seconds from all the action, and it has to perpetually repair itself to keep the cell alive. Enzymes perform up to 1,000 tasks a second, and they work like sped-up worker ants that build, inspect, and rebuild molecules. At actual speed, a cell is an incomprehensible place—but slowed down, it's more like a place where millions of objects perform millions of mundane tasks while perpetually bumping into one another.

Bryson expands on his metaphor of life inside the "nightmarish place" of a cell in order to highlight how much sheer activity goes on all the time inside cells in order to keep life going. Just as Bryson has stressed that it's a wonder that life arises at all, he now stresses how the mechanisms that keep it going are equally amazing.

The human heart has to pump 75 gallons of blood an hour to keep all the cells in a human body oxygenated. Mitochondria (tiny bacteria living in our cells) consume the oxygen and convert it into a molecule called ATP, which is like a little battery pack that gets passed around the cell and that powers everything up. Each cell contains about a billion ATP molecules, which are drained of power and replaced every two minutes.

Bryson stresses once again that life is highly dependent upon bacteria. In fact, without bacteria consuming oxygen and generating ATP, our cells wouldn't be able to function at all. Bryson thus emphasizes the interrelatedness of organisms on Earth in order to foster a sense of care for the way other species (including bacteria) are treated by humans.

When a cell is no longer needed, it's programmed to eat itself by breaking down its molecules so that they can be reused. Sometimes, a cell won't comply, and it starts dividing and multiplying instead, which is what we call cancer. Bryson says that cancerous cells are essentially "just confused cells." This happens so rarely—considering the decades of a lifespan—that cells really are "wondrous" in functioning so consistently en masse. Cells don't think—their activities are automatic—but they're nonetheless harmonious and ordered across the entire human body. Cell activity is directed by a molecule called DNA, which Bryson will discuss next.

Bryson emphasizes that the mechanism of life at the cellular level is, like every other aspect of life on Earth, something that humans take for granted without realizing how easily things could go awry. Cells that fail to function properly trigger cancer. When considered over the span of a lifetime, however, the fact that things go wrong so rarely is both "wondrous" and seemingly miraculous. Bryson believes that this, too, deserves our awe.

CHAPTER 25: DARWIN'S SINGULAR NOTION

Charles Darwin was advised that a book on pigeons would be more appealing to the public than his book *On the Origin of Species*, but he publishes it anyway. The book laid out the theory of evolution, and in 1859, and the first edition sells out within a day. As a child, Darwin struggles academically and tries unsuccessfully to study medicine and law before graduating with a degree in divinity. Darwin even winds up on his infamous five-year voyage around the world on the HMS *Beagle* by chance. The captain, Robert FitzRoy, chooses Darwin as a replacement dinner companion (after Fitzroy's first choice drops out) partly because FitzRoy enjoys conversations about Christianity, although Darwin's progressive attitude leads to many quarrels over the course of the voyage.

Bryson introduces the topic of evolution with intriguing personal anecdotes about Darwin's life, including the comical circumstances surrounding his presence on the HMS Beagle. *Once again, Bryson illustrates through this description that the scientific enterprise isn't dry, abstract, and boring. Rather, it's full of human stories that can be used to draw readers in and render scientific theories (this time, evolution) more palatable, memorable, and interesting to amateurs.*

Funnily enough, Darwin doesn't use the term "evolution" until the sixth edition of his book is published, preferring "modification by descent." Darwin also doesn't invent the idea of evolution itself, as the concept is already circling in scientific circles before he publishes his book, but rather provides a plausible explanation for *how* evolution happens. He realizes that life is a constant struggle for resources and that organisms with some built-in advantage will typically win the competition, survive to reproduce, and thus pass the advantage on. This means that species continually improve by growing more adaptable to their environment. The idea is captured in the phrase "survival of the fittest"—which, contrary to popular belief, isn't Darwin's phrase, but Herbert Spencer's.

Bryson stresses the power of a good description by highlighting the most famous catchphrase associated with evolution: "survival of the fittest." Even though the phrase isn't Darwin's own, it still becomes associated with his theory because it's so compelling. The fact that other scientists are circling around the idea of evolution at this time in history also means that Darwin's theory doesn't come out of left field—in fact, it makes good scientific sense. Bryson stresses this to show how damaging religious biases can be to scientific progress—even with the idea circulating in the air, it still takes a long time to be accepted.

When Darwin returns from his voyage, it takes him six years to sort through the specimens he has collected, and a further two years to sketch out his theory. He finishes it in 1844, but then—bizarrely—locks his manuscript away for years. Bryson says that Darwin "kept his theory to himself" for so long because "he knew well the storm it would cause" to postulate that humans arise without the help of a "divine creator." In fact, the only reason Darwin does publish his manuscript is because an acquaintance, Alfred Russel Wallace, independently comes up with a near-identical theory, and the two mutually agree to share their ideas in unison at a conference on July 1, 1858.

Bryson shows that although Darwin formulates his theory of evolution in 1844, he doesn't publish it until 1858 because he's afraid of religious persecution. In fact, without Wallace's intervention, Darwin might never have published his theory at all. Darwin's fear of causing religious controversy is thus directly responsible for holding back scientific research on evolution for over a decade, which shows that religious prejudices can significantly slow down scientific progress.

Wallace's reputation stumbles after he becomes interested in the occult, and Darwin becomes the father of evolution by default—though he's is "tormented" with religious guilt for years. Darwin refers to himself as "the Devil's Chaplain," and says that making the theory public feels like "confessing a murder" (presumably, God's murder). Critics are slow to adopt Darwin's view, citing an absence of adequate fossil evidence as their reason. Others, like T. H. Huxley believe that complicated organs like eyes can't slowly evolve, but must be conceived as a whole. The idea resembles theologian William Paley's 1802 "argument from design," which claims that the natural world is so complex that it must have been intentionally designed by God.

Bryson explains that Darwin's religious guilt prevents him from pursuing the topic of evolution further, underscoring that religious bias can often hinder scientific advancement. Religious prejudice further holds up progress because many of Darwin's contemporaries resist the idea of evolution for years because of their belief in life's emergence by divine creation.

A monk named Gregor Mendel, who crossbreeds pea specimens to compare inherited traits, makes the next scientific leap. Though Mendel doesn't use the word "gene," he argues that every seed contains "dominant" and "recessive" characteristics that predict which traits will be inherited by the next generation. Mendel presents his findings at a conference in 1865, but his "*too* scientific" approach (with countless technical details) fails to excite much attention. Between them, Darwin and Mendel lay the foundations of 20th-century life sciences: Darwin explains that innate advantages or characteristics facilitate evolution, and Mendel shows how such characteristics are passed on.

Once again, Bryson shows that a good scientific discovery is easily overlooked if it's poorly described. Mendel's "too scientific" and highly technical writing obscures the value of his important findings, and he fails to stimulate audiences to think about his ideas. Bryson uses this example to highlight how closely scientific progress and good expression are tied together, since writing that fails to engage scientists tends to be overlooked, even if it contains very good ideas.

Though Darwin doesn't explicitly say that humans are descended from primates, many assume that this is what he means. A conference is held, with thousands in attendance, to discuss the implications of Darwin's view for "the intellectual development of Europe." The discussion is so heated that the former HMS *Beagle* captain Robert FitzRoy holds a Bible aloft and yells, "the Book, the Book," in dismay, and one woman reportedly faints. Darwin, meanwhile, spends his "twilight years" studying the behavior of worms.

Bryson appeals to comedy—in describing people fainting or holding Bible's aloft—to stress that religious opposition to Darwin's theory is absurd and has no legitimate place in a scientific conference like the one Darwin speaks at. Darwin's hesitance to pursue the controversial topic further shows that religious biases interfere with scientific progress.

Darwin is never honored for his theory of evolution during his lifetime—it only gains widespread scientific acceptance in the 1930s and 1940s, when scientists combine Mendel and Darwin's views to generate a refined theory of evolution called the "Modern Synthesis." Bryson thinks it's funny that at the beginning of the 20th century, many scientists are "men" who think that science is "nearly at an end," when really, they haven't yet laid the foundations of modern biology.

In drawing his story about evolution to a close, Bryson quantifies how long it takes for scientists to finally accept evolution as a serious research area in order to stress that religious prejudice holds up scientific progress on evolution by almost a century. Bryson also pokes fun at patriarchy by emphasizing how many "men" have an over-inflated sense of confidence about their scientific achievements despite the fact that biology proper hadn't even begun at this point.

CHAPTER 26: THE STUFF OF LIFE

If a person traces their genealogy back eight generations, they have 250 direct ancestors. That number rises to a million at 25 generations and a billion at 30 generations—that's more people than existed back then, meaning that we all have common ancestors. Ancestrally, Bryson says, we're "all family." In fact, most people share 99.9 percent of their genes. Each of a person's cells has a nucleus, and each nucleus has 46 chromosomes which contain the instructions necessary to make an individual. Each chromosome is made of a "wonder" chemical called DNA, and each person have a lot of it—up to 20 million kilometers worth of DNA exists inside a human body. DNA has one purpose: to make more DNA. DNA isn't itself alive, but it is fundamental for life.

Bryson addresses DNA with the aim of instilling amazement in the reader about the building blocks of life. Once again, Bryson uses evocative writing to engage the reader, nesting scientific facts about DNA within imaginative descriptions that help the reader imagine DNA's complexity, so that they begin to feel a sense of wonder and curiosity about the building blocks of their own bodies.

A Swiss scientist named Johan Friedrich Miescher first discovers DNA in 1869, and other scientists discover chromosomes in 1889. Many scientists suspect that either chromosomes or DNA (or both) have something to do with heredity because they live inside every cell, but they know little else about them. In 1904, Thomas Hunt Morgan begins investigating chromosomes by breeding fruit flies, which have only four chromosomes. He's able to deduce that chromosomes have something to do with how traits are passed on, though even by 1933, some scientists still don't believe in genes. In 1944, Oswald Avery cross-breeds bacteria, decisively showing that DNA is the active agent in heredity.

Bryson stresses—as with most other aspects of science—how recent the scientific knowledge of heredity is. Though DNA is first discovered in the 1800s, it takes until 1944 for serious research to take off on a broad scientific scale, meaning that scientists have had less than a century's worth of research time to gain knowledge about DNA. This alludes to the fact that science still has a long way to go.

A decade later, four competing scientists in England—named Maurice Wilkins, Rosalind Franklin, Francis Crick, and James Watson—finally crack DNA's structure. Franklin, who's a woman, makes the most progress despite facing a lot of prejudice in the 1950s. Franklin isn't allowed to eat with other faculty and is often treated with a lack of respect, or "formalized disdain that dazzles modern sensibilities (actually any sensibilities)." Franklin is the only one with good results from her experiments, but she hides her images of DNA strands from the others—until Crick and Watson take them in 1953 "without her knowledge or consent." From Franklin's images, Crick and Watson learn that DNA is a double helix, and they go on to win the Nobel Prize for this discovery.

Bryson leverages his discussion of scientists competing to discover DNA's structure to show, once again, how patriarchy impinges on scientific research by making working conditions unpalatable for female scientists like Franklin, who have to eat separately and are treated as inferiors by their colleagues. Bryon stresses that despite this, Franklin makes the most progress on the hunt for DNA's structure, which shows once again that had male scientists in this era not let their sexism deter female colleagues, even more progress would have been made.

DNA's double helix shape looks like a twisted **rope ladder**: the rungs (or steps) of the ladder are formed by joining bases—specifically, G with C or A with T. The order in which the letters appear as they progress up the ladder is the human DNA code. When it's time to make a new DNA molecule, the ladder rips down the middle like a zipper, and each half goes to make a new partnership (or a new rope ladder). This happens in "a matter of seconds, which is quite a feat," according to Bryson. Most of the time, DNA replicates accurately so that each new ladder is an identical replica of the ladder it ripped away from.

Bryson symbolizes DNA as a rope ladder to help the reader visualize its double helix structure, and he uses the analogy of a zipper to represent the mechanism of DNA's replication. Once again, Bryson appeals to the reader's imagination, preferring metaphors over technical, dry, or abstract information, as he thinks this will be more engaging for the non-professional reader.

Sometimes, though, a letter gets in the wrong rung on the **rope ladder**—in technical terms, a "single nucleotide polymorphism" or "Snip" happens—and this can affect the body that the cells eventually turn into. It might mean that the human is worse off (say, they're more likely to get a disease), or better off (say, they have extra red blood cells). These slight differences play out to affect the likelihood of survival: they're the mechanism for Darwin's idea of natural selection. 99.9 percent of one's DNA is identical to every other human's, but the 0.1 percent difference is made up by one's Snips. Everyone's genome is thus slightly different—but only by a tiny margin.

Bryson continues the metaphor of the rope ladder to explain how evolution happens: when a component is placed in the wrong order (or "rung") of the ladder, the genetic qualities that the DNA builds will be slightly different. If it's to the person's advantage and they survive to reproduce, the new order will be preserved and passed on. Once again, Bryson stresses how human existence is largely a matter of chance—effectively, humans exist because of a very long chain of "Snips" that gradually change the bodies built by DNA.

Bryson says that all animals are, in a way, "slaves to their genes," which is why salmon and spiders are prepared to die during mating—the impulse to disperse genes trumps their impulse to survive. Scientists experimenting with cross-breeding species realize that humans share 60 percent of their genes with fruit flies and 90 percent with mice. It's hard to isolate genes for a specific trait, though, as most inherited traits arise from combinations of genes that are harder to pin down than single genes. The more we learn, the more complicated the picture seems, which is why cracking the human genome seems more like the beginning of something much bigger. So far, we know what genes are, but we don't really know how they work.

Bryson highlights—as with other aspects of science—that the more scientists delve into genetic research, the more complex things get, and the more they realize how little they actually know. There are many fundamental things that scientists don't know about genes beyond what they are and which ones belong to which animals. This means that genetic research, like all other scientific fields, is only at the beginning of its journey.

It turns out that scientists now also need to crack the human "proteome," a new concept capturing the information that creates proteins, which is far more complicated than the human genome. Despite the complexity of our genes, Bryson thinks it's a "profound" truth that we are closely related to everything on Earth—even half the chemical functions that happen in bananas also happen in humans, prompting Bryson to conclude that "all life is one."

Genetic research is so new, in fact, that concepts are still being developed to grasp the fundamental components of heredity (such as "proteome"), meaning that the foundations of this science are still being laid. Bryson also emphasizes how interrelated all living beings are in order to subtly imply that humans should not be so careless with species that share our planet with us.

CHAPTER 27: ICE TIME

In 1815, the largest volcanic explosion in 10,000 years takes place when an Indonesian mountain named Tambora explodes with the force of 60,000 atom bombs. The ash it expels diffuses worldwide, cooling the atmosphere slightly. Earth's climate is cooler in the 19th century than it is now, so it's hard for scientists of the time to imagine that their climate is much warmer than what Earth has witnessed in its past. In the 1700s, James Hutton hypothesizes that Earth might have had glaciers covering it in the past—but since Hutton is such an unclear writer, most of his ideas are overlooked by the scientific community.

Bryson revisits early geologist James Hutton in order to show once again that Hutton's profound insights—this time, about glaciers—might have triggered significant advances in geology had his writing not been so obtuse. Through this example, Bryson reiterates that poor expression hinders scientific progress. Bryson also shows how recent human knowledge of glaciers is, once again indicating that scientific knowledge in this area is still quite limited.

Although local folk knowledge already holds that unusual rock formations were transported from distant locations by glaciers, scientists are still slow to accept this hypothesis. A botanist named Karl Schimpher coins the term "ice age" in 1837, though Swiss naturalist Loius Agassiz formalizes the theory. Unfortunately, Agassiz's ideas are poorly-received. They only start to catch on after scientists make an expedition to Greenland for the first time and learn that parts of the world are covered in ice sheets. Curiously, James Croll—a university janitor who taught himself science from books in the university library—writes the most famous paper on the topic in 1864. He speculates that changes in Earth's orbit and its ice ages are related.

Bryson alludes, again, to how young the field is by showing that research on Earth's historical ice ages only gets going in the mid-19th century, indicating that it still has far to go. Bryson emphasizes James Croll's status as an amateur scientist to show that many profound scientific ideas come from non-professionals, which is why Bryson thinks scientific writing should strive to engage the wider populace (instead of being esoteric and obtuse) as that will only drive scientific progress forward.

Croll calculates that Earth's most recent ice age was 80,000 years ago, but geological evidence suggests a more recent ice age since then. In 1900, a Serbian mechanical engineer named Milutin Milankovitch realizes that Croll forgot to factor a variable into his calculations: namely, Earth wobbling on its axis. It takes Milankovitch years to do the calculations, but he eventually publishes a book in 1930, correctly arguing that Earth's wobbling on its axis accounts for its ice ages. Then, a meteorologist named Wladimir Köppen realizes that when summers are too cool to melt ice quickly, sunlight is bounced back by ice's reflective sheen, exacerbating the cooling effect.

Bryson emphasizes, through his discussion of Croll, Milankovitch, and Köppen, that the scientific endeavor takes a long time, and is often multi-generational, as scientists refine and build on the work that came before them until all anomalies are accounted for. Croll, Milankovitch, and Köppen's research findings also indicate, as before, how precarious life on Earth is—it takes only the slightest change to trigger substantive changes in Earth's climate.

In the 1970s, scientists calculate that if North America, Eurasia, and Greenland were just 300 miles north of where they are, they'd experience permanent ice ages, meaning that "we're very lucky." Bryson says that technically, we're actually in an ice age right now. 20,000 years ago, 30 percent of Earth's land surface was covered with ice. Now, 10 percent still is. Earth's longer history, however, shows that the planet is usually hotter and doesn't have permanent ice at all. In geological terms, the current ice age started 40 million years ago. Scientists think that the formation of the Himalayas is responsible, as this altered wind patterns. Consequently, Africa dried up, causing apes to climb down from trees and start living on the ground.

Bryson emphasizes once again how lucky humans are that things aren't even the slightest bit different—even with a minor amount of continental drift, over half the world's land surface would be inhospitable to humans. At the same time, human existence also depends upon ice ages—much like it depends upon extinctions—since the current ice age is a crucial factor in the evolution of humans. Once again, then, Bryson emphasizes how much our existence is a matter of sheer chance or the whims of the planet.

Earlier ice ages tended to be more dramatic: a "super ice age" happened about 2.2 billion years ago that might have caused the entire surface of the planet to freeze solid. Icy planets tend to stay frozen over, and it would have been that way for Earth had volcanic activity not disrupted the ice age—and as a result, triggered the Cambrian explosion. The thawing triggers violent weather that might be the closest Earth has come to wiping out life altogether. Ice cores from Greenland also show that Earth's historical climate is much more volatile than scientists think, though they have no idea why. Bryson says that there's "no reason to suppose that this stretch of climatic stability should last much longer."

Bryson continues stressing how much our existence depends upon luck: without a molten core to disrupt the "super ice age," Earth would have stayed permanently frozen over, and human life would likely never have evolved. As before, however, Bryson shows how this is a double-edged sword, since Earth's molten core also puts humans in peril on a daily basis. Once again, he wants the reader not to take the relative tranquility of Earth's recent climate for granted. Bryson also indicates that scientific knowledge about Earth's historical climate is highly limited.

Scientists even predict that, paradoxically, global warming might trigger more cloud cover, which would cause snowfall to linger and trigger another deep freeze—though it's hard to do more than speculate. Bryson says "much is simply beyond us." On the other hand, if humans end up melting ice through climate change, sea levels would rise by 200 feet, flooding every coastal city in the world. Curiously, we don't know which way the future will go. Bryson concludes that "Only one thing is certain: we live on a knife edge."

The fact that scientists think global warming might lead either to a dramatically warmer climate or a dramatically cooler one shows how little scientists know about predicting Earth's climate, meaning that there is—as always—a lot of scientific work ahead. The fact that things could go either way also shows how perilous human existence is: in both outcomes, life would be dramatically affected.

CHAPTER 28: THE MYSTERIOUS BIPED

In 1887, young Dutch doctor Marie Eugène François Thomas Dubois is in Sumatra looking for the earliest human remains on Earth on a "hunch," because he thinks that Sumatra is full of caves and that ancient humans lived in caves. Almost miraculously, he finds what he's looking for. At the time, early human fossil records consist of only five incomplete Neanderthal skeletons. Even these are met with resistance: one anthropologist suggests the Neanderthal's heavy brow ridge is caused by excessive frowning and that the skeleton is much more recent.

As before, Bryson introduces a new topic—here, bipeds, including other human-like species—with an anecdote that humanizes the scientific endeavor, in order to help engage the reader. Bryson has already mentioned that many scientists have historically resisted evolution on religious grounds, and once again, he notes how much hostility there is surrounding efforts to map the chain of human evolution.

Dubois's team find part of a skull that they think is the missing link between apes and humans. It's popularized as "Java Man." To Dubois's surprise, he's met with hostility from the scientific community upon his return to Europe, most of whom argue that the skull belongs to a gibbon. In 1924, anatomist Raymond Dart receives a complete child's skull that looks like it might be the missing link, and he dubs it "southern ape man of Africa." His claim, too, is met with hostility by the scientific community. Efforts multiply, and by the 1950s, there are so many disagreements about how to interpret skeletons that that some scientists argue for 100 different species of hominid.

Bryson shows that hostility to skeletons that might connect humans and apes on the evolutionary chain continues until the mid-20th century, eventually triggering widespread confusion about how to make sense of new skeletons that are found. Once again, Bryson highlights that religious prejudices often slow down scientific progress, subtly implying that fostering openness and combatting prejudices in the scientific endeavor is important.

F. Clark Howell's efforts to simplify the classification into two categories are largely rebuffed in the 1960s. Today, the picture is still in disarray. Bryson says some scientists think there are only two types of hominoid, others think there are 20, and very few agree on which ones are the right ones. Bryson says that part of the problem is lack of evidence. Scientists have to speculate about entire species based on a mere 5,000 partial skeletons from scattered ages in history—collectively, they'd fit in the back of a pick-up truck with room left over. The patchiness of the record is what makes each skull seem like radically different to the others, and it triggers many disputes.

Part of the reason why scientists struggle to piece together the period of history that captures the dawn of humankind is—as with other fossils—a lack of evidence. The record is so patchy that it's difficult for scientists to come to a consensus at all, indicating how little scientists know about early humans and how much discovery still lies ahead.

With all that mind, Bryson tentatively argues that for 99.99999 percent of our history, chimpanzees and humans were in the same ancestral line. Seven million years ago, the "australopithecines" (of many shapes and sizes) emerged from Africa's tropical forests and began roaming the savanna, becoming the dominant hominid species for five million years. The most famous specimen from this time is named Lucy: she's 3 feet tall, and she can walk as well as climb. In 2001 and 2002, additional bipedal specimens were found.

Bryson pieces together a sketchy history of the descent of apes from the trees and the evolution of bipeds, although his caution indicates that this picture is not much more than speculation based on highly limited evidence, once again showing that scientists have yet to gain an adequate grasp on this period in Earth's history.

Bipedalism is a risky evolutionary move—it demands completely reworking the pelvis and making the birth canal much narrower. This means that babies have to pass through with smaller brains, and they demand longer infant care post-birth. This is even harder for Lucy and her contemporaries, who have orange-sized brains. Bryson speculates that Lucy and her clan came down from the trees because they had to. Changing tectonic plate activity made forests sparser in Africa. Of the six or so hominid types living in Africa around 2 million years ago, only one survived: "Homo." Conventionally, "Homo habilis" (the first and most primitive species) comes first, and "Homo sapiens" (meaning us) comes last—but there's a disputed number of species in between, including "Homo erectus."

Bryson stresses that evolving to walk on two limbs entails a great deal of risk for early hominids. This highlights how lucky humans are to be here and how easily things could have gone south for our ancestors before we evolved. Bryson also shows that a lot of scientific confusion about hominids—specifically, how many species of hominid there are—persists in this research area, once again indicating that the vast majority of the scientific journey still lies ahead.

Scientists have no idea why the Homo brain suddenly started growing 2 million years ago. Ian Tattersall thinks it might be an evolutionary accident. Nobody knows why the other hominoids disappeared, though Matt Ridley suggests that humans ate them. Tattersall says it's hard for humans to accept that our existence is just an accident and that there's nothing "inevitable" about it, but that may well be the case. Homo erectus is considered the dividing line between humans and apes. Scientist Alan Walker describes Homo erectus as a fearsome creature: "the velociraptor of its day."

As scientists try to piece together the evolution of humans, they discover more questions—such as why hominid brains grew and what happened to the other hominids—indicating the limited scope of their knowledge. The fact that brain growth might be an accident of history shows, once again, how lucky humans are to exist at all.

Richard Leakey discovers the first near-complete Homo erectus skeleton in the 1980s, of a nine- to 12-year-old boy who died 1.54 million years ago. Leakey believes that Homo erectus skulls show evidence of a capacity for speech (which chimps lack), though Walker disagrees. The spread of Homo erectus around the globe is so fast that some scientists think another hominid genus might have spontaneously arisen in Asia. Bryson says that all scientists *do* know is that about a million years ago, bipedal beings left Africa and spread around the globe. Everything else remains a matter of speculation.

Scientific knowledge of early bipeds is still largely a matter of speculation, and scientists still disagree on fundamentally important factors like how hominids spread throughout the world and whether all humans come from the same hominid ancestors. The sheer amount of speculation about these fundamental aspects of human history shows that scientists have barely begun to piece together this part of our story.

CHAPTER 29: THE RESTLESS APE

About 1.5 million years ago, some hominid took a stone and used it to shape another, creating a teardrop-shaped axe: the first piece of advanced technology in the world. Scientists find thousands of these in Africa, suggesting that hominids even made them for fun. The absence of human fossils makes it extremely difficult to piece together this early history, and there are many mysteries. The traditional view holds that humans spread out of Africa in two waves: the first, Homo erectus, left and evolved into Neanderthals. Then, about 100,000 years ago, a smarter species—Homo sapiens—arose and spread, displacing Neanderthals (though the method of displacement—whether murder, disease, or sheer competition for resources—is unknown).

Bryson reemphasizes that nearly all of early human history is a complete mystery to scientists. The amount of speculation, once again, indicates that this scientific endeavor is only in its infancy. The fact that there are multiple hominid species competing for resources in this early period of history—including Neanderthals and Homo sapiens (us)—shows how easily humans might not have existed at all. Though it's unclear why Neanderthals disappear, there's a good chance that luck (for Homo sapiens) has something to do with it.

Curiously, scientists know less about early Homo sapiens than "almost any other line of hominids." The earliest record of Homo sapiens dates back to 100,000 years ago in modern-day Israel. Neanderthals were surprisingly hardy, survived in harsh cold climates, and had much larger brains than modern humans. Some scientists even suggest that Neanderthals didn't so much disappear as blend in with us. Alan Thorne's multiregional hypothesis holds that ancient Homo erectus left Africa for Asia and Europe, and then each region evolved independently. Opponents reject this idea because it encourages the view that some modern races are superior to others—something that Carleton Coon controversially argues.

Bryson continues to stress how little scientists know about the early history of humans. He also unveils further mysteries that continue to elude us about our past as we learn more about it, such as how to account for the larger brains of Neanderthals compared to humans. The disappearance of the Neanderthals could also serve as a cautionary tale for humans, reminding us of how easily we ourselves might disappear—though even this speculation, like everything else, is tentative.

Anomalies continue to arise. DNA sampling of a 62,000-year-old "Mungo Man" fossil of Australia shows that it's distinct from human DNA. This evidence questions the idea that all humans came from Africa. Other genetic discrepancies continue to arise, and geneticists don't know what to make of these anomalies. Population geneticist Rosalind Harding thinks "we've barely begun" unraveling the history of our species. Harding also explains that it's extremely easy to contaminate a specimen with more modern DNA, so she thinks radical claims should be "treated dubiously."

The more data scientists uncover, the more questions they have. This indicates that the task of scientific discovery may, in fact, never reach a point of completion, since more information yields more anomalies that need to be continually accounted for. The high margin for error also shows how fallible scientific claims can be, further indicating that there is always work for scientists to do.

Bryson visits Rift Valley in Kenya and sees ancient tool beds from 1.2 million years ago. Bryson's guide, Jillani Ngalli, explains this area was an ancient factory for turning stones into tools—but nobody knows which hominids are responsible for it. Ngalli concludes that "it's all a mystery."

As Bryson draws his story about early hominid history to a close, he's left with no other conclusion than the fact that all scientists know for sure is, paradoxically, how little they know—the "mystery" remains to be solved by future scientists.

CHAPTER 30: GOOD-BYE

Bryson explains that the dodo becomes extinct before 1700, entirely as a result of humans killing dodos for recreation. Humans even destroyed the last remaining evidence of dodos, meaning that we have little information about what they actually looked like. Wherever humans exist, Bryson says, species go extinct. Depending on the continent, the rise of humans coincides with the extinction of 50-95 percent of large animal species. Bryson thinks that humans have destroyed may wondrous species, such as ground sloths the size of a house and turtles the size of cars, leaving the planet severely "diminished" because of our activities. Today, scientists even estimate that human-caused extinction runs 120,000 times higher than it ever has in history.

Bryson emphasizes how bizarre it is that humans treat other species with such carelessness. We are the trigger for an unimaginable amount of extinctions—up to 95 percent of land species in some continents—and our killing rates are only increasing. This is especially troubling considering that all life is interrelated, meaning that our actions not only have disastrous consequences for other species, but can also impact our own ability to survive as a species.

In the 1990s, Australian naturalist Tim Flannery, along with his artist friend Peter Schouten, embarks on a question to find out more about the species that have gone extinct in the time of humans, resulting in a "moving" book called *A Gap in Nature*. Flannery and Schouten show that some extinctions (like the dodo's) are the result of human cruelty, while others happen because humans are "majestically foolish." For example, a lighthouse worker's pet cat unwittingly kills the only known species of flightless perching birds. Similarly, the Carolina parakeet is hunted to extinction because it's considered a pest; the last surviving one dies in captivity, but the zoo loses its carcass.

Another problematic aspect of the "foolish" activities of humans beyond extinctions themselves is the way we ourselves get in the way of scientific progress. The careless ways that humans treat important scientific artifacts (such as the last dodo and the Carolina parakeet bodies) directly impinge scientific research, meaning that our sabotaging will result in ever-more work for scientists to do. Bryson also discusses Flanner and Schouten's book to illustrate what good, engaging science writing looks like. Bryson thus argues that the need to engage humans with good writing is even more important when science deals with matters of literal life and death—especially the survival of entire species.

Two 19th-century collectors named Lionel Walter Rothschild and Hugh Canning independently amass huge collections of taxidermy animals, but also end up making some species go extinct through their collecting efforts, including the koa finch of Hawaii. Another collector named Alanson Bryan similarly kills the last black mamos birds, which he's curiously happy about. In the early 20th century, many institutions even pay handsomely for the bodies of rare animals, further exacerbating extinction rates.

Bryson has already argued that humans recklessly endanger our environments, such as the oceans and the atmosphere, with pollution. Now, he discusses Rothschild, Canning, and Bryan to stress how carelessly humans also treat other species on the planet. All this could a have devastating impact on life's ability to thrive.

All this considered, Bryson says, nobody in their right mind would choose humans to be the caretakers of life on Earth. Yet somehow, that's what humans are. In some ways, we're life's "worst nightmare." We don't even know how many species we've killed. Bryson says that life is such a rare achievement in the harsh conditions of the universe that we are extremely lucky to be here—and even luckier to be intelligent enough to reflect on our luck and appreciate our existence. So far, humans have survived on the basis of "lucky breaks," but we'll need more than that if we want to keep life going—even for our own species.

Bryson closes his book with a cautionary tale: he has argued throughout that human existence is extremely rare, terrifyingly perilous, and extraordinarily lucky. The last thing humans should be doing, then, is undermining our own survival or the survival of other species. Bryson aims to leave his readers with a sense of awe for the planet and its many life forms, so that they will be motivated to take better care of the only home humans have and strive not to destroy ourselves, but to keep life going.

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