The Disappearing Spoon

INTRODUCTION

BRIEF BIOGRAPHY OF SAM KEAN

Sam Kean was born in Sioux Falls, South Dakota and is very proud of his hometown. Kean earned a bachelor's degree in English and physics at the University of Minnesota Twin Cities and a master's degree in library science at Catholic University of America. *The Disappearing Spoon* is his first book and it was both a critical and commercial success. It became a bestseller and was nominated by the Royal Society as one of the top 10 science books of 2010. Kean's other books similarly focus on making science accessible to a general audience, often by using entertaining and unexpected stories from the history of science. Along with Kean's four books, he writes for magazines such as *The Atlantic* and *The New York Times Magazine*. He also regularly appears on the radio and gives guest lectures across the world. He lives in Washington, D.C.

HISTORICAL CONTEXT

Many historical events are covered in the novel, beginning with what is arguably the very first historical event—the Big Bang. Kean traces the history of the universe, along with our galaxy and solar system, detailing how Earth and the other planets were formed. He also provides an account of the speculation around how the dinosaurs died out. Jumping ahead in time, Kean mentions scenes from Ancient Greece, such as the Spartans' (largely unsuccessful) attempt to use chemical weapons against the Athenians. He also considers how Plato's theory of the forms relates to the contemporary scientific understanding of the elements. The majority of the book, however, focuses on the period between the Age of the Enlightenment and the present—particularly from the 19th century onwards, as this is when the periodic table was devised. Key historical events that the book covers within this period include the Australian gold rush, the discovery of DNA, and the Manhattan Project, in which the first nuclear bomb was developed.

RELATED LITERARY WORKS

Only one year after the publication of *The Disappearing Spoon*, another popular science book focusing on the periodic table of elements was also published. This one, Hugh Aldersey-Williams's *Periodic Tales: A Cultural History of the Elements, from Arsenic to Zinc*, also provides information about the elements through quirky, unexpected facts and historical narratives. Other popular science books about the periodic table include Tim James's *Elemental: How the Periodic Table Can Explain (Nearly) Everything* and James M. Russell's *Elementary: The Periodic Table Explained*. Looking more broadly, many other books cover science and its history for a lay audience. These include Richard Holmes's *The Age of Wonder*, which chronicles the boom of scientific research in the 18th and 19th centuries; Carl Sagan's *Cosmos: A Personal Voyage*, which accompanied the famous TV series of the same name; and Richard Rhodes's *The Making of the Atomic Bomb*, which focuses on some of the same material that appears in *The Disappearing Spoon*.

KEY FACTS

- **Full Title:** The Disappearing Spoon: And Other True Tales of Madness, Love, and the History of the World from the Periodic Table of the Elements
- **Where Written:** Washington, D.C.
- **When Published:** 2010
- **Literary Period:** Contemporary
- **Genre:** Nonfiction; Pop Science
- **Setting:** The book spans the history of the universe from the Big Bang to the present; many of its stories take place from the 19th century onward, after the periodic table was invented.
- **Point of View:** Third Person

EXTRA CREDIT

Changing Minds. In interviews, Kean has stated that he was aware that many readers probably have an automatically unfavorable view of the periodic table, imagining it to be boring. He hopes that *The Disappearing Spoon* will convince them otherwise.

Failed Experiment. Although *The Disappearing Spoon* received generally positive reviews, the review featured in *The New York Times* protested that the book doesn't "really unpack how the periodic table works."

PLOT SUMMARY

In the introduction, Kean recalls how he was fascinated by the mercury inside thermometers as a child. Discovering mercury was an element prompted his interest in **the periodic table**. In *The Disappearing Spoon*, Kean hopes to tell stories about the ways in which the periodic table interacts with human culture. Most people are familiar with the table but they might be intimidated or uninspired by it. Kean explains basic features of the table, such as the fact that every element is necessary—if a single one were removed, the whole thing would no longer make sense. He also explains that for the elements, "geography is destiny," meaning that their position on the periodic table determines what properties they have.

Kean then explains the structure of atoms, which are made up of particles called protons, neutrons, and electrons. He describes the different parts of the period table, which contain groups of elements such as noble gases, halogens, rare earths, acids, alkalis, and transition metals.

Kean states that life on Earth is carbon-based but that some science fiction writers have speculated alien life-forms might be based on silicon, the element below carbon on the periodic table. While this is plausible to a degree, silicon also has properties that make it an unlikely basis for life-forms. Kean also discusses germanium, an element which, together with silicon, had a chance to become widely used in electronic technology. Ultimately, silicon won (hence the name "Silicon Valley").

Kean tells the story of Robert Bunsen, after whom the Bunsen burner is named, used a spectroscope to study the light produced by elements, which led to huge advances in them. However, it was only after this that Dmitri Mendeleev just developed the first version of the periodic table, which would be subject to much revision in later years.

For a long time, scientists assumed that all the elements had always existed. However, this theory then shifted to an understanding that at the very beginning of the universe, during the Big Bang, the only elements that existed were hydrogen, helium, and lithium. All the rest of the elements were formed inside stars. The solar system was formed when a star imploded and exploded again, becoming a supernova, and released a dust cloud that formed into our sun and planets. The age of Earth was first accurately calculated by a graduate student named Clair Patterson, who used the system of radioactive dating to produce the number 4.55 billion years.

Kean shifts to discuss chemical warfare, which was used all the way back in Ancient Greece but only became advanced during World War I. One German scientist, Fritz Haber, dedicated himself to developing particularly brutal chlorine and bromine weapons that had horrifying effects on victims. He also developed a method of capturing nitrogen that was used to make ammonia, a fertilizer that has grown food for billions of people around the world.

In 1939, the American physicist Luis Alvarez heard about the German scientist Otto Hann's research into nuclear fission, the process of splitting a uranium atom. At the time, understanding of radioactivity was still at a fairly early stage. The U.S. and its allies initiated a research program, **the Manhattan Project**, which aimed to study nuclear fission with the eventual goal of developing atomic weapons. The Project used a strategy of experimental calculations called the Monte Carlo method, which later became the basis of using computer calculations in scientific research.

Later on, during the Cold War, there was a competitive race between the U.S. and the Soviet Union to find new elements and name them. Kean discusses two scientists, Linus Pauling and Emilio Segrè, who—despite being enormously talented—are remembered for committing two of the most awful mistakes in scientific history. While mistakes can often advance scientific progress, the errors Pauling and Segrè made were decidedly not that kind of mistake.

Elements can often be poisonous. In early 20th-century Japan, cadmium from the Kamioka mines infused nearby rice fields and led to local people experiencing an illness known as "*itai-itai*" or "ouch-ouch." Meanwhile, elements like thallium and polonium have been used to deliberately poison people. In the 1990s, a young American named David Hahn poisoned himself by trying to build a nuclear reactor in his backyard.

Many elements also have great medicinal use but they can be unpredictable when they interact with the human body—for better or worse. For example, when a U.S. candidate for Senate, Stan Jones, ingested silver for its health benefits, he ended up turning blue. Two scientists, Gerhard Domagk and Louis Pasteur, broke scientific rules by administering drugs that were still in an experimental phase to patients in an informal context. Fortunately, in both cases the risk paid off and the patients were healed. Similarly, Pasteur's research on drugs that prevented bacteria from multiplying led to the development of antibiotics.

Elements can be unpredictable and deceptive. For example, modern prosthetics were developed when a Swedish doctor named Per-Ingvar Brånemark attached a titanium window to view the open inside of a rabbit, then realized that the cells of the rabbit's skin bonded to the titanium. As a result of this finding, titanium came to be used in prosthetics.

Beyond the chemical elements themselves, Kean also addresses the personal and professional obstacles that scientists have faced over the years in the midst of working with these elements. Marie Curie was one of the most important scientists in history, although she nearly missed becoming a scientist at all thanks to the restrictions on women's education in Warsaw, Poland, where she was born. Curie won two Nobel Prizes, one in Physics and one in Chemistry, and she shaped the earliest understandings of radioactivity. Lise Meitner, meanwhile, was an Austrian scientist of Jewish descent who had a productive collaboration with a German colleague, Otto Hahn, until he betrayed her by taking all credit for their work while she was in hiding during World War II.

In addition to medicinal and military uses, elements also have an important role in the history of money: they have often been used as currency and thus were also used by counterfeiters. At only 23, the scientist Charles Hall found a way to isolate the aluminum that is naturally bonded to oxygen in the earth's crust, thereby paving the way for aluminum to be mass-produced for household use. He made a fortune with this discovery.

Throughout scientific history, the problem of pathological science—beliefs that use scientific-seeming tools to appear legitimate, but are actually false—has been a recurring problem. Yet even in serious, hard science, deception has occurred. One of the most egregious cases involved B. Stanley Pos and Martin Fleischmann, two scientists who claimed to have discovered cold fusion but in reality fudged their data.

Pivoting from his discussion of pathological science, Kean discusses contemporary research into the periodic table. This often involves cooling elements to ultra-cold temperatures, where they behave differently to how they would normally. Albert Einstein, working in tandem with the Indian scientist Satyendra Nath Bose, realized that if atoms are cold enough, they can condense into a new state of matter. This was a major discovery, although it was years before the technology was available to get atoms cold enough to actually prove it correct. More fields at the cutting-edge of current periodic table research include bubble science (studying bubbles leftover from chemical decay) and the related field of froth science (studying element bubbles from inside rocks).

In the book's penultimate chapter, Kean discusses national bureaus of standards and measurement, which work to ensure scientific precision to a formidable degree. Recently, such bureaus (and the scientific community in general) have been grappling with the possibility that one of science's fundamental constants—a principle called alpha, which is tightness of the connection between electrons and a nucleus—might not actually be constant after all. The prospect that alpha could be increasing (even if only by a tiny and gradual amount) has revolutionary implications for science.

At the end of the book, Kean lists some further cutting-edge research on the elements currently occurring. He argues that the current version of the periodic table, while still highly important and useful, is not the only possible version. He dreams about a huge variation of possible tables and wonders how they would correspond to what an alien species would use to depict the elements.

CHARACTERS

MAJOR CHARACTERS

Sam Kean – The author of the book. Kean is a science writer who majored in physics and English in college. His fascination with **the periodic table** began when he was a child and he used to let mercury thermometers drop on the floor so he could look at the element inside. In *The Disappearing Spoon*, Kean's dual interests in English and science shine through: rather than presenting the history of the chemical elements in a technical manner, he compiles a "storybook" of anecdotes that feature human struggle and triumph. As such, he adds emotional appeal to what lay readers might otherwise consider to be dry or difficult to understand material. Kean's other books also focus on making science more accessible to a general audience.

Maria Goeppert-Mayer – A German scientist who won the Nobel Prize in Physics for devising the nuclear shell model of an atom's nucleus. She married an American chemist, Joseph Mayer, and worked alongside him after finding herself shut out of opportunities due to her gender. Her work on the atomic nucleus led to her being appointed professor at UC San Diego.

Fritz Haber – A German scientist who helped develop the use of bromine and chlorine chemical weapons during World Wars I and II. Haber also developed ammonia fertilizer but he seemed more interested in weaponry. The Nazis used his research to develop Zyklon B, the gas used in the mass murder of Jewish people during the Holocaust.

Ernest Rutherford – A New Zealander/British scientist at the University of Manchester whose many contributions to scientific knowledge included identifying that atoms had a compact, positively-charged nucleus. Rutherford was also one of the founders of the field of bubble science. He supervised a large number of students who went on to make enormous contributions to the field.

Emilio Segrè – An Italian Jewish scientist who escaped World War II and settled in the U.S. Segrè's many contributions to science included discovering the elements technetium and astatine. However, he is also remembered for committing one of the biggest blunders is scientific history by missing the opportunity to discover nuclear fission, which was lying right in front of him.

Otto Hahn – A German scientist who worked in close collaboration with Lise Meitner. When the Nazis came to power, Lise was forced to flee to Sweden. Hahn continued to correspond and meet with Meitner in secret, but when the Nobel committee awarded the Physics prize to him alone, he did not mention that she was his collaborator and had done much of the work he was credited for.

Victor Ninov – A member of a UC Berkeley research team that competed with Russian and West German teams to find the remaining elements in **the periodic table**. When the other countries' teams tried to replicate Berkeley's experiment, it was discovered that Ninov faked some of his data by inputting false positives. Ninov was subsequently fired and his team was disgraced.

Linus Pauling – A scientist who revolutionized the field of chemistry by outlining how quantum mechanics determines the chemical bonds that form between atoms. However, Pauling also made a career-defining error: he made an incorrect estimate about the shape of DNA. Pauling then ignored the warnings of both one of his graduate students and his son, Peter, that his guess was wrong and that James Watson and Francis Crick had discovered the correct shape.

Marie Curie (née Skłodowska) – One of the most important scientists in history. Born in Warsaw, Poland, she moved to France and married Pierre Curie, a fellow scientist with whom she collaborated. She discovered radium and polonium and won two Nobel prizes, one in Chemistry and one in Physics. She died of leukemia caused by all the radiation exposure that occurred in the course of her research. Marie and Pierre's daughter, Irène, eventually died the same way.

György Hevesy – A Hungarian aristocrat who studied radioactivity at the University of Manchester under the direction of Ernest Rutherford. After successfully turning meat radioactive after injecting it with radium-D, Hevesy moved to Copenhagen to work with Niels Bohr. Working with a team led by Bohr, found element 72 on his first attempt.

Lise Meitner – An Austrian scientist of Jewish descent who collaborated with Otto Hahn. When the Nazis came to power, Meitner was turned into the authorities by a colleague and was forced to flee to Sweden. She continued her collaboration with Hahn long-distance and made the revolutionary discovery that Enrico Fermi had discovered nuclear fission. Hahn ultimately allowed the Nobel Prize committee to give him full credit for their joint work, but when this was eventually discovered, the element named after him—hahnium—was renamed meitnerium after Meitner.

William Crookes – An English chemist who was inducted into the elite Royal Society at the age of only 31. Shortly after, Crooke's brother died at sea; consumed by grief, Crookes embraced the fad of spiritualism and even attempted to make a scientific argument for the plausibility of communicating with the dead. He later renounced spiritualism.

King Midas – A character from Greek mythology who was based on a real king. In the myth, a satyr gives King Midas the ability to turn anything he touches into gold—which Midas soon realizes is more of a curse. It is believed that the myth originates in the fact that the real King Midas lived near an abundant source of brass, which people may have mistaken for gold.

MINOR CHARACTERS

Gilbert Lewis – An influential American scientist and founder of the UC Berkeley chemistry department, which played a huge role in the history of **the periodic table** and is often considered the best chemistry department in the world.

John Bardeen – Bardeen developed a germanium amplifier alongside Walter Brattain in 1947 and was awarded the Nobel Prize in Physics in 1956.

Walter Brattain – Brattain developed a germanium amplifier alongside John Bardeen in 1947 and was also awarded the Nobel Prize in Physics in 1956.

William Shockley – An electrical engineer and physicist who attempted to build a silicon amplifier. On learning about Bardeen and Brattain's germanium amplifier, he (successfully) made it look as if he also deserved credit for the invention and was co-awarded the Nobel Prize with them in 1956.

Jack Kilby – An electrical engineer from Kansas who built the first integrated circuit, thereby revolutionizing electronic technology.

Robert Bunsen – A German scientist who didn't actually invent the Bunsen burner, but rather improved the existing model. Bunsen was left half-blind by an explosion that happened in his lab. He used a spectroscope in order to advance early understanding of the elements.

Dmitri Mendeleev – A Russian scientist who developed the first version of **the periodic table**. An eccentric person, Mendeleev was eventually fired from his professorship for being an anarchist.

Paul Emile François Lecoq de Boisbaudran – A French scientist who discovered gallium.

Johann Friedrich Böttger – A teenage German alchemist who, at the turn of the 18th century, was arrested by King Augustus of Poland and ordered to help Ehrenfried Walter von Tschirnhaus develop a technique for making porcelain. The two succeeded.

Ehrenfried Walter von Tschirnhaus – Von Tschirnhaus worked for King Augustus of Poland at the task of making a porcelain recipe.

Johan Gadolin – A Swedish-Finnish scientist who discovered six of the 14 lanthanides in **the periodic table**.

Clair Patterson – Patterson used radioactive dating to give the first accurate estimate of the age of Earth while he was a graduate student at the University of Chicago in the 1950s.

Luis Alvarez – An American physicist who—along with his son Walter—developed the asteroid theory about why the dinosaurs died.

Walter Alvarez – A geologist who developed the asteroid theory of dinosaur extinction along with his father, Luis.

Richard Muller – Muller theorized that the sun has a twin star, Nemesis, that influences events in the solar system.

Otis King – A Nebraskan banker who owned the mining rights to the only source of molybdenum in the world. He was pressured by Max Schott to sell the rights for a low price.

Max Schott – An employee of a mining company in Frankfurt who successfully pressured Otis King and the workers at the Colorado molybdenum line to turn their supply over to his company.

Henry Moseley – A scientist based at the University of Manchester who discovered a mathematical relation between the atomic number of an element, the number of protons in its nucleus, and the wavelength of the X-rays created when a beam of electrons strikes the nucleus.

Edwin McMillan – Edwin McMillan worked with Emilio Segrè trying to find element 93. After Segrè mistakenly concluded that their experiment was unsuccessful, McMillan persevered on his own and he ended up being awarded the Nobel Prize in Chemistry in 1957.

Stanislaw Ulam – A Polish scientist who helped to turn the Monte Carlo method used in **the Manhattan Project** into the basis for the modern use of computational calculations as a research tool.

Leo Szilard – The inventor of the cobalt bomb, an especially brutal and horrifying nuclear weapon.

Glenn Seaborg – A Nobel-prize winning UC Berkeley professor who was a team leader on **the Manhattan Project**. He collaborated with Al Ghiorso, and together they discovered more elements than any other individual or team of scientists, filling out much of the periodic table.

Noboru Hagino – The Japanese scientist who realized that the "*itai-itai*" illness was being caused by rice fields soaking up toxic cadmium from a nearby mine.

Graham Frederick Young – A British serial killer who poisoned people using thallium.

Gerhard Domagk – A German scientist who helped discover the "handedness" model of biomolecules along with Louis Pasteur. Domagk saved the life of his daughter, Hildegard, who fell ill from an infection after injuring herself with a sewing needle.

Louis Pasteur – A French scientist who discovered the "handedness" model of biomolecules along with Gerhard Domagk. His research also led to the development of antibiotics and the pasteurization method of killing harmful bacteria in milk.

William Knowles – An American chemist whose research formed the origin of drug synthesis. His work on L-dopa, an amino acid similar to the neurotransmitter dopamine, revolutionized the treatment of Parkinson's disease.

Per-Ingvar Brånemark – A Swedish scientist who accidentally discovered that the flesh of mammal bonds with titanium, paving the way for the use of titanium in prosthetics.

Niels Bohr – A Danish physicist who made significant contributions to the fields of atomic structure and quantum theory. People were so impressed by Bohr's work that there were rumors he had prophetic abilities. He won the Nobel Prize in Physics in 1922.

Kazimierz Fajans – A Polish chemist who discovered brevium (which was subsequently renamed protactinium). Fajans narrowly missed winning the 1924 Nobel Prize for Chemistry for reasons that remain unclear.

Paddy Hannan – An Irish gold prospector who found a source of gold in Australia, nicknamed "Hannan's Find."

Isaac Newton – An 18th-century English physicist and astronomer who is one of the most influential scientists in history. Newton developed the laws of motion and gravitation that were eventually overturned by Albert Einstein's theory of relativity.

Primo Levi – An Italian Jewish writer and chemist who survived incarceration in Auschwitz concentration camp. He wrote about his experiences in several highly influential texts, including a book called *The Periodic Table*.

Charles Hall – An American chemist who devised a way to separate aluminum from oxygen at the age of only 23. He made a fortune from mass-producing aluminum.

László Moholy-Nagy – A Hungarian artist, designer, and professor at the Bauhaus,. Moholy-Nagy invented the theory of forced versus artificial obsolescence.

B. Stanley Pons – An American electrochemist once considered to be one of the greatest scientists in history, who was disgraced when it was revealed that his and Martin Fleischmann's claim to have discovered cold fusion was based on deliberate misrepresentation of their results.

Martin Fleischmann – A British chemist who falsely claimed, along with B. Stanley Pons, to have discovered cold fusion. He was subsequently disgraced.

Wilhelm Röntgen – A German mechanical engineer and physicist who accidentally discovered X-ray imaging.

Robert Falcon Scott – A British explorer who led what he hoped was the first team to travel to the South Pole. Upon reaching the Pole, not only did Scott realize the Norwegians had got there first, but he and his team died trying to make the return journey.

Albert Einstein – A German Jewish theoretical physicist who is considered one of the greatest scientists of all time. He invented the theory of relativity.

Werner Heisenberg – A German theoretical physicist who is one of the most important figures in the development of quantum mechanics. His uncertainty principle is, as Kean points out, widely misunderstood among the public.

Satyendra Nath Bose – An Indian theoretical physicist who helped discover Bose-Einstein Condensate along with Albert Einstein.

Donald Glaser – An American physicist who helped found the field of bubble science.

Lord Kelvin (William Thomson) – Lord Kelvin, whose given name was William Thomson, worked with Ernest Rutherford and was a pioneer in the field of bubble science.

Seth Putterman – A scientist and professor at UCLA who also worked in the field of bubble science and discovered an important connection between the nonreactive quality of noble gases and sonoluminescence.

Alexander Shlyakhter – A Soviet scientist who studied the only known natural nuclear fission reactor and controversially argued that alpha, one of the most important fundamental constants in physics, might be gradually changing.

Frank Drank – An astrophysicist who developed the Drake Equation, a calculation that shows that it is likely that there are 10 alien "sociable civilizations" in our galaxy alone.

Richard Feynman – A hugely influential American theoretical physicist.

Joseph Mayer – An American chemist married to fellow scientist Maria Goeppert-Mayer.

Clara Immerwahr – Fritz Haber's wife, who begged him to stop his involvement in developing chemical weapons. She failed to do so and ended up killing herself.

Al Ghiorso – A technician who worked with Glenn Seaborg to discover a record number of elements.

Carlo Perrier – An Italian scientist who worked with Segrè to find element 43.

Peter Pauling – Linus Pauling's son, who was a graduate student at the University of Cambridge at the time the shape of DNA was discovered.

James Watson – A graduate student at the University of Cambridge who discovered the double helix shape of DNA.

Francis Crick – A graduate student at the University of Cambridge who discovered the double helix shape of DNA along with James Watson.

Ernest Lawrence – An American scientist who developed the cyclotron, an "atom smasher" that could be used to produce a large number of radioactive elements at once.

Friedrich Miescher – The scientist who originally discovered DNA in 1869.

Rosalind Franklin – An English scientist at the University of Cambridge whose research was central to the discovery of the double helix shape of DNA.

William Bragg – James Watson and Francis Crick's advisor at the University of Cambridge.

Hildegard Domagk – The daughter of Gerhard Domagk.

Pierre Curie – A scientist and the husband of Marie Curie, with whom he collaborated. Pierre was killed in a street carriage accident in 1906.

Irène Joliot-Curie – Daughter of Marie and Pierre Curie. Irène was also a scientist and, like her mother, she died of leukemia caused by radiation exposure.

Carl Sagan – An American scientist and author known for the saying, "We are all star stuff," which reflects the fact that all matter on Earth is comprised from the same chemical elements as stars and other planetary bodies.

King Augustus of Poland – King of Poland between 1694-1733.

Marco Polo – A 14-century Italian merchant and explorer who travelled to Asia and brought back goods to Europeans, such as porcelain.

Antonio Salazar – The dictator of Portugal between 1932-1968.

Field Castro – A Cuban communist revolutionary who was the leader of Cuba between 1965-2011.

Alexander Litvinenko – A former KGB agent who defected to the UK and was poisoned to death there with the element polonium.

Tycho Brahe – A sixteenth-century aristocrat and astronomer whose nose was cut off in a drunken duel. He commissioned a replacement nose made from either silver or copper.

Stan Jones – A libertarian candidate for the U.S. senate who ingested silver over fears Y2K would make it impossible to access antibiotics. The element turned his skin blue.

Franklin Delano Roosevelt Jr. – An American lawyer and politician; the son of Franklin Delano Roosevelt and Eleanor Roosevelt.

Adolf Hitler – Leader of the Nazi party and Chancellor of Germany between 1934-1945.

Mahatma Gandhi – Leader of the anticolonial movement in India, who among other activities organized the Salt March of 1930 in protest against the British colonial government's salt tax.

Bertrand Russell – A major British philosopher who was famous for, among other things, presenting philosophical arguments in favor of atheism.

Johann Wolfgang von Goethe – Von Goethe is considered by many to be the greatest German writer in history. He also dabbled in science, although he had no skill in it.

Kenneth Parker – An American businessman and inventor of the Parker 51 pen.

Mark Twain – An American writer fascinated by science and technology.

Robert Lowell – An American poet widely considered to be one of the greatest poets of the twentieth century. His life was blighted by severe bipolar disorder until he was able to start taking the element lithium as treatment.

Bertha Röntgen – Wilhelm Röntgen's wife.

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.

STORYTELLING AND SCIENCE

In *The Disappearing Spoon*, Sam Kean argues that storytelling is a vitally important part of scientific knowledge and can play a key role in enhancing understanding of science, particularly for non-experts. He drives this message home using his own personal perspective as someone who has always been interested in science yet is drawn more to writing and narrative than he is to conducting experiments in a lab. While the reader of *The Disappearing Spoon* may not emerge with a comprehensive knowledge of how the periodic elements work in a practical sense (at least not as much as they would from a textbook or a chemistry course), the book does provide a thorough, wide-ranging, and deliberately entertaining group of stories that situate the elements in different contexts. Kean ultimately shows that having the contextual information provided by the elements' narratives is more useful than just knowing about the way elements work in a purely scientific, isolated, and abstract sense. Furthermore, he uses narrative to make **the periodic table** more accessible and relevant by showing how the elements play a role in every aspect of existence. He also challenges unjust and untrue narratives that are often rooted in sexism and other forms of prejudice.

Kean argues that the periodic table is "both a scientific accomplishment and a storybook"—each element is not just a substance in the universe, but the central subject of a set of stories. A selection of these narratives is collected in *The Disappearing Spoon*, which is itself the "storybook" Kean mentions. The book includes stories of how an element was discovered, how it has been used to advance technology, and the negative side effects of an element, such as its capacity to poison people or be used as a weapon. Most—though not all—of the stories involve humans, and thus *The Disappearing Spoon* is a "storybook" that situates the elements in relation to humanity via narrative.

Through Kean's use of narrative, he challenges the idea that science is a dry, dull discipline, instead showing that science can be filled with excitement, surprise, terror, and awe. Indeed, it is through storytelling that Kean conveys the *emotional* component of science. For example, the narrative about the German chemist Fritz Haber demonstrates the full range of emotion that scientific discovery can produce. Haber's discoveries were used to both positive and negative ends, but his focus was always on their most destructive side: the production of gas weapons of war. Kean tells the story of how Haber's wife, Clara (a talented scientist herself), tried to stop him from producing these gas weapons and how Haber didn't listen. This emotionally rich and poignant story draws on human emotion and interpersonal conflict while also educating readers on the chemical elements involved, thus illustrating that scientific research is anything but dull.

Kean's use of scientific stories also makes the periodic table more accessible in the sense that he shows different levels on which the periodic table is relevant to existence. The narratives he includes range from the most large-scale and important (e.g., the Big Bang) to far more minor tales, such as the story of the C.I.A.'s idea of making Fidel Castro's hair fall out by powdering his socks with thallium. The inclusion of these relatively unimportant and silly stories makes the book entertaining, but it also serves as a key reminder that the elements play a role in every aspect of existence. The periodic table is not just relevant to major, foundational phenomena like the Big Bang, DNA, and nuclear weapons—it is equally relevant to all the mundane and trivial aspects of life.

Another way in which Kean's use of scientific narrative makes the periodic table more relevant to a wider group of people is his inclusion of *counternarratives* that challenge accounts which are widely accepted but actually false. One example of this is the story of how Lise Meitner, an Austrian physicist of Jewish descent, did not receive credit for her role in discovering protactinium due to the combination of sexism and antisemitism. Kean lays out the full story of Meitner's collaboration with the German chemist Otto Hahn, her flight from Nazi Germany, and the way in which the discovery of protactinium ended up being entirely attributed to Hahn. When Hahn won the Nobel Prize, he omitted Meitner's involvement in the story of his research. In replacing a false narrative with a correct one, Kean further highlights how scientific narratives are wrapped up with interpersonal conflicts and wider societal issues of justice. Telling scientific stories, then, is not just an effective way to teach people about the periodic table—it is also a necessary aspect of making science fair and ethical.

EXPERIMENTATION, ACCIDENTS, AND DISCOVERY

One of the main subjects of *The Disappearing Spoon* is how the elements of the periodic table were discovered. By including a diverse variety of discovery stories, Kean shows that learning about new elements often involves accidental circumstances. This relates to one of the fundamental paradoxes of scientific discovery: at its core, discovery is the process of finding something that already exists before definitively knowing that it exists. The fact that such discoveries must involve both knowledge and lack of knowledge makes it unsurprising that accidents are so often necessary to the process. At the same time, Kean also highlights an important distinction between the importance of accidents and the rigor with which experiments must be performed in order to *prove* that an element exists. Accidents might give an initial hint of a new discovery, but it is only after performing an experiment many times, according to exact specifications, that this discovery can be proven to be true.

One of the most extraordinary aspects of the book lies in Kean's depiction of how completely random accidents can lead to scientific invention and discovery. For example, he explains how the German chemist Robert Bunsen's experiments with arsenic led him to experience damaging side effects that included hallucinations. This, in turn, encouraged Bunsen to develop an antidote to arsenic poisoning. When Bunsen's work with arsenic eventually caused an explosion that left him half-blind, this didn't turn him off experimenting—it actually encouraged him to "indulg[e] his passion for natural explosions," pursuing further research in this area. His research helped him develop the famous scientific tool named after him: the Bunsen burner. Another example of accidents (and even failures) leading to discovery is when the early German alchemist Friedrich Böttinger was captured by King Augustus of Poland because he'd heard Böttinger was impressing crowds by making two silver coins "disappear." Although Böttinger wasn't able to repeat his trick for the king, his imprisonment put him into contact with Ehrenfried Walter von Tschirnhaus, who had been trying to find a way to make porcelain. Working together, the two men were finally able to devise a successful method where others had failed for centuries.

Yet while Kean provides a host of examples of accidents leading to discovery, he also shows that not all accidents ultimately lead to the increase of (accurate) scientific knowledge. In Chapter 8, for example, Kean explores the story of Linus Pauling and Emilio Segrè, who, despite being great scientists, "will forever be united in infamy for making two of the biggest mistakes in science history." Before narrating the details of Paulding and Segrè's mistakes, Kean emphasizes that "mistakes in science don't always lead to baleful results," providing a host of examples of times when mistakes led to important discoveries. However, in Pauling and Segrè's case, there wasn't a fortunate outcome to their errors: Segrè overlooked the fact that his research produced both nuclear fission and the elusive element 43 of **the periodic table**, while Pauling combined mistaken intuitions with "bad data" to draw incorrect conclusions about DNA.

While overall Kean shows that accidents (and even mistakes) are vital to discovery, he does emphasize that no discovery is proven true until it is subject to rigorous scrutiny through repeated experimentation. Unless a scientist goes through this process, their discovery will not be considered valid—and will be vulnerable to being proven wrong like in the cases of Segrè and Pauling. Indeed, Kean spends the penultimate chapter of the book discussing the extraordinary lengths to which scientists go in order to achieve absolute precision in their experiments. He explains that the scientists most devoted to precision are those who work in national standards bureaus, and that to these scientists, "measurement isn't just a practice that makes science possible; it's science itself." Clearly, there isn't any room for accidents or mistakes in this realm of science—the whole function of standards bureaus is to eliminate error to the greatest degree possible. Yet as the book shows, this dedication to precision doesn't actually contradict the importance of accident within the scientific process. Precision makes experiments repeatable, and the accurate repetition of experiments is the only way in which discoveries—which often occur as the result of accidents—are confirmed to be true. In this sense, accidents and precise experimentation are linked as two vital parts of scientific discovery.

NATURE VS. CULTURE

Although the central subject of *The Disappearing Spoon* is **the periodic table**, the book is not particularly focused on the elements themselves. Instead, Kean explores the role that the periodic elements play within human culture. He does so by telling stories about the lives of scientists; explaining how elements are discovered and used; and showing how the periodic table interacts with cultural phenomena such as art, war, mental instability, religion, and money. In doing so, Kean shows that the periodic table should be considered a human invention even though it describes the "natural" world. Indeed, Kean blurs the distinction between nature versus human culture, and even suggests that it might be impossible for humans to access any understanding of nature that is not also a human invention in some sense.

The idea that the periodic table is a human invention (rather than a purely natural fact) is conveyed by the language Kean uses throughout the book. Not only does he call the periodic table a "storybook," he also compares it to a castle designed by an architect. These metaphors emphasize the idea that the periodic table has been constructed by humans. Even though it describes the universe in an accurate manner, it is still a human invention that translates the natural universe into something humans can understand and use for our own purposes.

Of course, just because the period table was invented by humans doesn't mean it doesn't accurately describe real substances that exist outside of human perception (although, as any philosopher and many scientists would point out, the existence of a reality beyond human perception is subject to debate). Kean continually reminds the reader that the periodic table thwarts scientists' efforts to master it. For example, Kean details how a long succession of scientists, including Emilio

Segrè, tried and failed to find element 43 of the table. While humans may have devised a framework through which to understand the elements with the periodic table, this framework does correspond to a reality that has its own rules and attributes that function beyond human control. As a result, element 43 evaded the grasp of scientists for many years.

At other points in the book, Kean emphasizes a fusion between nature and culture, and it is this idea of a meeting point that most accurately describes his depiction of the periodic table. For example, Kean shows how World War I, World War II, and the Cold War all triggered intensified investment in scientific research, usually with the aim of developing weapons. Yet in the process of trying to invent weapons that would be used for purposes limited to human culture, scientists made major breakthroughs in understanding the way the natural world operates. The most extreme example of this is, of course, the development of nuclear weapons. Many would argue that the atomic bomb is humanity's worst invention, a representation of the most terrible and destructive side of human culture. Yet at the same time, this invention constituted an extraordinary moment in humanity's understanding and manipulation of the physical universe.

Another way in which Keane demonstrates the meeting of nature and culture is by examining how human bias can negatively affect science. The most common example he cites in the novel is the way scientists have been historically discriminated against due to their gender or ethnic background. This is not only unjust, it also hinders scientific progress: when discrimination occurs, scientific knowledge gets lost, misattributed, or misunderstood in the process. Ridding science of the biases and flaws of human culture as much as possible is thus vital to achieving a better understanding of the natural universe.

SCIENCE FOR GOOD VS. FOR EVIL

While Kean generally writes with a tone of admiration and wonder for **the periodic table**, he is also clear about the fact that the elements have been put to both good and evil uses. Indeed Kean provides many examples of negative and destructive uses of science alongside positive ones. These include poisoning (both deliberate and accidental), chemical weapons, and the unimaginable devastation caused by nuclear bombs. Yet, at the same time, Kean shows all the positive and progressive uses to which the elements have been put. These include a host of advances in medical technology, chemical fertilizer which has mitigated the problem of hunger, and the use of cold fusion as a renewable, nonharmful source of energy. Ultimately, the extremes of good and evil uses to which the chemical elements have been put shows that the elements themselves cannot be considered to have any kind of inherent moral value, good or bad. Instead, they are simply tools that can be put to either good or evil uses.

In many ways, *The Disappearing Spoon* is a testament to the positive, productive ends to which the elements can be put. For example, Kean cites the example of the "gentleman astrologer" Tycho Brahe, whose nose was cut off in a duel in 1564. Brahe ordered "a replacement nose of silver," which archaeologists later found out was actually made of copper when they found Brahe's remains. Both elements (copper and silver) are antiseptic and thus they play an important role in medicine. Indeed, Kean links the story of Brahe's prosthetic nose to a story much later in history, in 1976, when mysterious bacteria entered the air vents of a hotel in Philadelphia, making hundreds of the guests sick and killing 34 of them. (The sickness was later called Legionnaire's Disease.) As a result of this disaster, copper started being used in air and water systems due to its antiseptic powers, which prevented similar tragedies from occurring again. This is far from the only example of the elements' potential to mitigate harm and improve human life. Kean also points to the use of lithium as treatment for bipolar disorder, as well as Stanley Pons and Martin Fleischmann's discovery of cold fusion, which can be used to create energy without generating harmful emissions. These examples suggest that there are myriad ways in which the elements can be used to the good of humanity. The more research is conducted on the elements and the more that is understood about them, the more likely it is for the elements to be put to productive, positive uses.

However, Kean also cites many examples of the elements' harmful uses, which generally result from a lack of knowledge about the way the elements work. Robert Bunsen's blindness and Irene Joliot-Curie's leukemia, for example, were both caused by unexpected explosions that might have been avoided with greater knowledge of the elements with which these scientists were experimenting. Similarly, the *itai-itai* disease that struck Japan for centuries was caused by cadmium released into water by zinc mining. As Kean points out, it took 12 centuries for people to understand that cadmium was the cause of this disease and that it was produced by the zinc mining process. Finally, Kean also gives the example of two disasters that took place at NASA due to uncertainty about the behavior of gases inside a spacecraft that was still on Earth. In the first disaster in 1961, three technicians were burned alive, while in the second, 20 years later, two died of nitrogen poisoning. In both cases, it wasn't until the disaster had already happened that scientists came to understand *why* they happened. Of course, for the unfortunate technicians who lost their lives, this knowledge came too late. These examples demonstrate how the periodic elements, like many other scientific discoveries, often cause accidental harm due to human error or ignorance.

Sadly, however, the destructive power of the elements is sometimes unleashed intentionally: Kean provides additional examples of how the elements have also been deliberately put to violent use throughout human history. Examples of this include the development of chemical weapons, the development of the atomic bomb, and the stories of people such as Graham Young, a British a British man who killed several people by poisoning them with thallium. Kean repeatedly invokes the figure of Faust, a German folkloric figure who sold his soul to the devil in exchange for unlimited knowledge and power, in order to represent the destructive power of science, particularly in relation to the problem of hubris (excessive pride in one's own powers). For example, in telling the story of the scientist Fritz Haber—who passionately dedicated himself to developing chemical weapons used to horrific effect in World Wars I and II—Kean characterize Haber as one of the "petty Fausts who twist scientific innovations into efficient killing devices." The book makes clear that while such "Fausts" are relatively few and far between in scientific history, they pose a very real and dangerous threat. In their hands, the elements—which can be used for good—become dangerous tools of destruction.

THE EXPANSION AND LIMITS OF HUMAN KNOWLEDGE

The Disappearing Spoon provides a summary of the knowledge that humans have acquired thus far about the elements and an account of how this knowledge was acquired. However, Kean makes clear that the process of learning about **the periodic table** is far from over. He does this by showing how knowledge about the periodic table has grown continuously over many centuries and has been subject to constant revision. Humanity may know more about the elements than ever before, but that does not mean the process is complete—all the knowledge that exists is provisional and it will continue to grow in the future.

Kean shows that human knowledge is limited and still evolving by pairing established facts with unresolved questions. One example of this occurs in Chapter 4, in which Kean traces how scientists gradually developed the Big Bang theory and how they used knowledge about the periodic table to accurately estimate when and how each of the planets in the solar system were formed. Yet, in the same chapter, Kean discusses major ongoing disputes within the scientific community, such as the debate over how dinosaurs went extinct. He compares two different theories: one blaming the extinction of the dinosaurs on a single-impact asteroid, the other on a possible star paired with the sun called Nemesis. In doing so, Kean shows how the uncertainty and fierce debate around the death of the dinosaurs produced new scientific knowledge. This scientific disagreement demonstrates how the limits and doubts that exist within human knowledge can be productive. Moreover, by juxtaposing ongoing debates with seemingly established facts, Kean points out that no scientific fact is guaranteed to remain "true" forever. Something might be believed to be true for centuries, only to have further evidence destabilize this truth. Scientific knowledge is always growing, and the way it grows if often through argument and uncertainty.

The part of the book most explicitly dedicated to the limits of human knowledge is the final chapter, Chapter 19. In this chapter, Kean explores the future of the periodic table, including elements that may have yet to be discovered. Currently, the rarest element (as far as anyone knows) is astatine. Kean describes this element as "a paradox" and argues that "resolving the paradox actually requires leaving behind the comfortable confines of the periodic table." The irony here is obvious: in order to advance human knowledge of the periodic table, the framework of the periodic table itself must be temporarily abandoned. The reason necessitating this abandonment is that there is a group of elements—what Maria Goeppert-Mayer called the "magic" elements—that behave in a way counterintuitive to what the periodic table teaches one to expect. While heavier elements are generally less stable and have shorter lifespans than lighter elements, the opposite is true for elements that come after uranium on the table. Elements past this point thus exist on what has been called the "island of stability." The elements that may yet to be added to the periodic table are not just novel substances—they may actually have "novel properties." These new elements and their unexpected properties may well challenge the existing principles of the periodic table, forcing scientists to make revisions to what are now fairly long-established facts. However, as Kean demonstrates throughout the book, this is not a cause for lament—instead, it represents exciting new opportunities. The limits of human knowledge mean that science is always provisional, and that the universe is always capable of surprises.

SYMBOLS

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

THE PERIODIC TABLE

The most important symbol in the book is also its central subject: the periodic table of elements. This table contains all known chemical elements, the building blocks of the entire universe, and thus symbolizes all that can be captured by scientific knowledge. At the same time, Kean emphasizes that the table is not a wholly natural entity. It is also a human invention, with an assortment of very human stories attached to it. In this way, the table also represents the confluence of humankind and the natural world. Early in the book, Kean argues that the table is a kind of "storybook" and he proceeds to tell some of the many stories contained within the table over the course of the text. Of course, this assertion is a metaphor: to most people, the periodic table does not remotely resemble a storybook but instead looks like a rather dry scientific chart patterned with a jumble of letters and numbers. Part of what Kean aims to achieve in the book is to show that this dull veneer hides a much richer truth filled with surprising, entertaining, heart-warming, tragic, and terrifying stories.

Indeed, Kean's depiction of the periodic table very much emphasizes its human side alongside scientific descriptions of how the different elements function and how they came to be arranged in this particular order. He describes the table as a "castle," which underlines its manmade quality. At the same time, Kean emphasizes that the table is also not really manmade. This becomes most clear in his descriptions scientists' efforts to find unknown elements and how elements thwart these efforts, evading capture. Ultimately, Kean shows that the periodic table is neither totally a human invention nor totally a natural entity—rather, it is both, and this is one of the many reasons why it is so fascinating.

THE MANHATTAN PROJECT

The Manhattan Project was a 1939-1946 research program designed to investigate and construct the first atomic weapons in history; as such, it represents the most sinister and evil side of science. The Manhattan Project shows how seemingly innocent, neutral, and important research—such as the mission of understanding the structure of the atom, and particularly the nucleus—can be twisted to yield horrific results. As Kean emphasizes throughout the book, science has sadly always played an important role in warfare, and this has become more and more prominent as scientific knowledge and technology have advanced. Indeed, the Manhattan Project (which took place during World War II) shows how times of war can be a perverse kind of catalyst for scientific advancement. This is because governments devote huge amounts of money and other resources in order to gather the best minds together in order to work tirelessly and single-mindedly on a particular project.

The Manhattan Project is perhaps the preeminent example of such (sinister) acceleration of progress. Scientists working on the project developed a new research method, the Monte Carlo Method, which involved running a large number of calculations in order to test which were (on average) most successful. This was transformative, as it combined elements of theoretical and experimental scientific research while also constituting a new method entirely. The Monte Carlo Method ended up stimulating the advance of computing, which—as is very clear from a contemporary perspective—completely revolutionized not just science, but the world. Unfortunately, the same is of course true for the Manhattan Project's main purpose, as the project culminated in the successful construction and deployment of two nuclear bombs. These caused unimaginable devastation and launched the cold war, which was defined by intense fears over the use of atomic weapons. Overall, then, the Manhattan Project shows how scientific progress is often tied to the very worst and most evil sides of humanity. Even seemingly innocent or neutral research can be used to terrible ends, and the technologies that are important to humans today often have chilling origins.

QUOTES

Note: all page numbers for the quotes below refer to the Back Bay Books edition of *The Disappearing Spoon* published in 2011.

Introduction Quotes

I latched on to those tales, and recently, while reminiscing about mercury over breakfast, I realized that there's a funny, or odd, or chilling tale attached to every element on the periodic table. At the same time, the table is one of the great intellectual achievements of humankind. It's both a scientific accomplishment and a storybook, and I wrote this book to peel back all of its layers one by one, like the transparencies in an anatomy textbook that tell the same story at different depths.

Related Characters: Sam Kean (speaker)

Related Themes:

Related Symbols:

Page Number: 7-8

Explanation and Analysis

At the beginning of the book, Kean has explained how as a child, he used to let mercury thermometers fall out of his mouth when he was sick and smash on the floor. The mercury fascinated him and he desperately searched for stories about the element everywhere he could find them. In this passage, Kean notes that mercury is far from the only element with narratives attached to it. Indeed, *every* element has many stories through which it can be understood. As Kean notes, these stories are not dry and dull but instead entertaining, surprising, and moving.

This quotation uses multiple metaphors to describe both the periodic table and the book Kean has written. The periodic table is "both a scientific accomplishment and a storybook," indicating that science and narrative are not as opposed as some people might assume—just because something occurs in the realm of hard science doesn't mean it can't also be understood through narrative. Kean then uses the metaphor of an anatomy textbook that peels back the different layers of a body in order to describe what he is seeking to do in *The Disappearing Spoon*. Essentially, there are different layers at which the periodic table can be understood. *The Disappearing Spoon* does not require the most technically complex or accurate layer of understanding, as it instead delves into the historical and cultural context of the periodic table. In doing so, the book can enhance lay readers' understanding of the actual science behind these anecdotes along the way while keeping them engaged.

❝❝ The periodic table is, finally, an anthropological marvel, a human artifact that reflects all of the wonderful and artful and ugly aspects of human beings and how we interact with the physical world—the history of our species written in a compact and elegant script.

Related Characters: Sam Kean (speaker)

Related Themes:

Related Symbols:

Page Number: 8

Explanation and Analysis

Kean has described the periodic table as a "scientific accomplishment" and also called it a "storybook." In this quotation, Kean provides yet another metaphor through which the periodic table can be understood. It might not initially be obvious that there is much difference between calling the table an "anthropological marvel" versus a "storybook." Indeed, both metaphors emphasize that a humanistic approach to the table is a useful and important way of understanding it. Yet while the storybook metaphor emphasizes narrative, there are, of course, stories that don't involve humans, such as the story of the Big Bang or the extinction of the dinosaurs.

The phrases "anthropological marvel" and "human artifact," meanwhile, place heavy emphasis on the idea that the periodic table is not a natural phenomenon but a human construction. Of course, the table has is based in the physical universe, but as an entity, it was designed by humans to be understood and used by humans. Consequently, as Kean emphasizes here, the periodic table reflects human culture; one can turn to the periodic table to gain a greater understanding of human history.

Chapter 1: Geography is Destiny Quotes

❝❝ People are used to reading from left to right (or right to left) in virtually every human language, but reading the periodic table up and down, column by column, as in some forms of Japanese, is actually more significant. Doing so reveals a rich subtext of relationships among elements, including unexpected rivalries and antagonisms. The periodic table has its own grammar, and reading between its lines reveals whole new stories.

Related Characters: Sam Kean (speaker)

Related Themes:

Related Symbols:

Page Number: 31

Explanation and Analysis

Kean has explained the idea that "geography is destiny," meaning that the location of an element on the periodic table determines its properties. In this quotation, Kean argues that while many people might automatically choose to read the periodic table horizontally, it is actually more important to focus on the vertical relationships between the elements.

Kean's use of the words "reading," "subtext," and "grammar" again emphasizes the literary aspect of the periodic table, which he has previously compared to a "storybook." In doing so, he suggests that the periodic table shouldn't necessarily be straightforwardly understood—rather, it should be *interpreted*, like a work of literature. This passage also indicates how the biases created by human culture can prevent people from interpreting the periodic table in the best manner. People might assume that the periodic table should be read horizontally just because this is how most human languages work. Truly understanding the periodic table therefore often involves unlearning the biases and instincts that human culture instils in each person.

Chapter 3: The Galápagos of the Periodic Table Quotes

❝❝ The discovery of eka-aluminium, now known as gallium, raises the question of what really drives science forward—theories, which frame how people view the world, or experiments, the simplest of which can destroy elegant theories.

Related Characters: Sam Kean (speaker), Paul Emile

François Lecoq de Boisbaudran, Dmitri Mendeleev

Related Themes:

Related Symbols:

Page Number: 54

Explanation and Analysis

Kean has told the story of Dmitri Mendeleev, the Russian scientist credited with inventing the periodic table. Mendeleev had both brilliant insight into the way that the known elements worked and a visionary skill at predicting the properties of elements yet to be discovered. While this made him a genius with an important place in scientific history, it could be annoying for fellow scientists like Paul Emile François Lecoq de Boisbaudran, who actually discovered an element Mendeleev predicted to exist ("eka-aluminum"). In this passage, Kean ponders whether it is the theories of visionaries like Mendeleev or the proofs of people like Lecoq de Boisbaudran that "drive science forward."

There is no question that both theories and experiments are necessary parts of science, as one could not exist without the other. Some might argue that it is pointless to ask which "really drives science forward," as both are indispensable. Moreover, theories and experiments work together—theories provide the framework that guides and enables experiments, while experiments are necessary to test if theories are true. At the same time, the importance of theories versus experiments changes across different contexts and historical moments. As such, Kean once again portrays science as something that is intimately tied to and shaped by the course of human history; both theories and experiments are much more than data on a page.

Chapter 5: Elements in Times of War Quotes

❝❝ With cheap industrial fertilizers now available, farmers no longer were limited to compost piles or dung to nourish their soil. Even by the time World War I broke out, Haber had likely saved millions from Malthusian starvation, and we can still thank him for feeding most of the world's 6.7 billion people today.

What's lost in that summary is that Haber cared little about fertilizers, despite what he sometimes said to the contrary. He actually pursued cheap ammonia to help Germany build nitrogen explosives […] It's a sad truth that men like Haber pop up frequently throughout history—petty Fausts who twist scientific innovations into efficient killing devices.

Related Characters: Sam Kean (speaker), Johann Wolfgang von Goethe, Fritz Haber

Related Themes:

Page Number: 83-84

Explanation and Analysis

Chapter Five explores the use of the elements in warfare. Kean has explained that chemical weapons were used back in Ancient Greece and also at the very beginning of World War I, but in neither of these instances were they particularly effective. He explains that the advancement of chemical warfare can be credited to a German scientist named Fritz Haber, who invented a process of capturing nitrogen from the air and turning it into ammonia. Here, Kean describes how ammonia was used for extraordinary good—as a fertilizer that fed (and continues to feed) billions of people—as well as terrible evil. Moreover, there is no ambiguity over the fact that Haber was far more interested in the evil outcomes of his research than the good.

Haber's malevolent motivations might surprise readers. One might (perhaps naïvely) assume that scientists are motivated by noble goals such as increasing knowledge; advancing human progress; or mitigating ills like hunger, disease, and death. Yet while this may be true for the majority of scientists, Kean points out that people like Haber are, unfortunately, not uncommon. He compares these people to Faust, the character from German folklore famously represented by writers such as Johann Wolfgang von Goethe and Christopher Marlowe. In these narratives, Faust is a scholar who gives his soul in a deal with the devil in order to gain unlimited knowledge and power. With this comparison, Kean suggests that the human tendency to search for knowledge can actually be a destructive one, as it may lead people to forgo any sense of morality or empathy in order to achieve greatness.

❝❝ In 1919, before the dust (or gas) of World War I had settled, Haber won the vacant 1918 Nobel Prize in chemistry (the Nobels were suspended during the war) for his process to produce ammonia from nitrogen, even though his fertilizers hadn't protected thousands of Germans from famine during the war. A year later, he was charged with being an international war criminal for prosecuting a campaign of chemical warfare that had maimed hundreds of thousands of people and terrorized millions more—a contradictory, almost self-canceling legacy.

Related Characters: Sam Kean (speaker), Clara

Immerwahr, Fritz Haber

Related Themes:

Page Number: 87

Explanation and Analysis

Kean has told the terrible story of Fritz Haber, a German Jewish convert to Lutheranism who has a highly contradictory scientific legacy. On one hand, Haber developed a process of turning nitrogen from the air into ammonia, creating an industrial fertilizer that revolutionized farming. At the same time, he also tirelessly worked at developing brutal chemical weapons, taking pride in his work and continuing even after his wife, Clara Immerwahr, begged him not to and then killed herself. This quotation discusses the contradictory legacy of Haber, who was granted the Nobel Prize for his work and condemned as a war criminal almost immediately after.

These two very different reactions to Haber's career highlight the fact that it is not just the choices of individuals but the nature of the world—and of the field of science—that enables scientific innovations to be used for both good and bad purposes. While World War I was occurring, Haber was rewarded (at least by the German government) for the work he did to advance chemical warfare. However, after the war ended, it was decided that Haber violated international law and he was duly punished. (The German government turned on him too, expelling him after the Nazis came to power due to his Jewish ancestry.) Haber may have been a rather straightforwardly malevolent person, but the way his research was rewarded one moment and punished the next shows that the ambiguity around scientific ethics is not limited to individual scientists, but much larger forces, too.

Chapter 6: Completing the Table...with a Bang Quotes

But notice the dates here. Just as the basic understanding of electrons, protons, and neutrons fell into place, the old-world political order was disintegrating. By the time Alvarez read about uranium fission in his barber's smock, Europe was doomed.

Related Characters: Sam Kean (speaker), Otto Hahn, Luis Alvarez

Related Themes:

Page Number: 106

Explanation and Analysis

Luis Alvarez was a young physicist at UC Berkeley when he learned about the research being conducted by Otto Hahn into uranium fission, the process of splitting a uranium atom's nucleus. Alvarez was overcome with excitement about this research and what it could reveal about the nature of radioactivity, atomic structure, and the atomic nucleus in particular. However, there was a problem: this was 1939, and the world was on the precipice of war. As this quotation shows, problems of human culture were at risk of majorly hindering what should have been a moment of thrilling scientific progress.

This passage thus demonstrates the way in which human culture—and particularly its nastiest sides of war, fascism, and genocide—interrupt the scientific process. Indeed, one of the rhetorical questions the book raises is how much could have been achieved scientifically if it weren't for problems such as global conflict, petty jealousy, sexism, and other social ills. In order for science to progress well, global cooperation is essential. Unfortunately, the reality of human existence means that cooperation across lines of gender, race, and nationality is often jeopardized.

Chapter 8: From Physics to Biology Quotes

Now, mistakes in science don't always lead to baleful results. Vulcanized rubber, Teflon, and penicillin were all mistakes. Camillo Golgi discovered osmium staining, a technique for making the details of neurons visible, after spilling that element onto brain tissue. Even an outright falsehood—the claim of the sixteenth-century scholar and protochemist Paracelsus that mercury, salt, and sulfur were the fundamental atoms of the universe—helped turn alchemists away from the mind-warping quest for gold and usher in real chemical analysis. Serendipitous clumsiness and outright blunders have pushed science ahead all through history.

Pauling's and Segrè's were not those kind of mistakes.

Related Characters: Sam Kean (speaker), Emilio Segrè, Linus Pauling

Related Themes:

Page Number: 137

Explanation and Analysis

Linus Pauling and Emilio Segrè were prominent figures in the race to discover new elements. Both made fundamental contributions to science, yet despite their importance, few non-specialists have heard of them. They are also significant because both made enormous mistakes in their careers, and in this passage, Kean explains that mistakes are not always a bad thing in science. Indeed, accidents and mistakes are actually part of what drives science forward. Although this might seem surprising, it actually makes sense: much of what science involves is discovering new information—yet how does one discover something before it is known?

Of course, there are many ways around this apparent paradox, from trial and error to making educated guesses based on similar phenomena to speculating using the theoretical branches of the discipline. Nonetheless, mistakes and accidents still play an important role in revealing information about the universe that humans might not have figured out themselves. At the same time, however, Kean humorously reminds the reader that not every scientific mistake is a success—in the cases of Pauling and Segrè's mistakes, they were instead humiliating failures.

Chapter 10: Take Two Elements, Call Me in the Morning Quotes

Obscure elements do obscure things inside the body—often bad, but sometimes good. An element toxic in one circumstance can become a lifesaving drug in another, and elements that get metabolized in unexpected ways can provide new diagnostic tools in doctor's clinics.

Related Characters: Sam Kean (speaker)

Related Themes:

Page Number: 167

Explanation and Analysis

In the previous chapter, Kean examined the history of poisonous elements, which have caused damage to humans under both accidental and deliberate circumstances. Yet while poisonous elements might be scary, they are at least reassuringly predictable. In the opening to Chapter Ten, Kean explains that many elements do not have such a logical, predictable impact on the human body—in fact, many elements behave in contradictory ways under different circumstances. What might be poisonous in a certain context is lifesaving in another.

This quotation conveys the high stakes and difficulty involved in experimenting with elements—and particularly "obscure" elements—for medicinal purposes. It can be hard to know in advance what the ultimate effect of an element on the human body will be. Furthermore, this quotation illustrates the neutrality of the natural world, which can be used for profound good or profound harm. Elements themselves are not inherently constructive or harmful—rather, the effect they have depends on the context in which they are used and, again, is often difficult to predict with any certainty.

Chapter 12: Political Elements Quotes

The human mind and brain are the most complex structures known to exist. They burden humans with strong, complicated, and often contradictory desires, and even something as austere and scientifically pure as the periodic table reflects those desires. Fallible human beings constructed the periodic table, after all [...] The periodic table embodies our frustrations and failures in every human field: economics, psychology, the arts, and—as the legacy of Gandhi and the trials of iodine prove—politics. No less than a scientific, there's a social history of the elements.

Related Characters: Sam Kean (speaker), Mahatma Gandhi

Related Themes:

Related Symbols:

Page Number: 203

Explanation and Analysis

In the previous chapter, Kean discussed the unpredictable and often deceptive ways elements behave when interacting with the human body. At the end of the chapter, he recounted the story of the Salt March led by Mahatma Gandhi in protest against the oppressive British colonial salt tax. He also noted the negative effects of the widespread distrust of iodized salt in India, which has led to multiple generations' worth of nutritional deficiency and birth defects, among other problems. In this quotation, which opens the following chapter, Kean reflects on the fact that the periodic table is made by flawed humans and thus cannot escape being a flawed object itself. The periodic table might aspire to scientific objectivity and purity, but nothing constructed by humans could ever fully achieve this.

Kean's words here provide a helpful justification for why a social history of the periodic table is so important. Examining the science alone can be useful, but it doesn't tell the full story. Adding contextual information about the historical, cultural, and political influences on the development of the periodic table enhances understanding of the science—particularly because, as the reader has seen, scientific errors are often intimately connected to social issues. Due to human fallibility, even the greatest scientists can have their knowledge obstructed by bias, prejudice, and egotism. Understanding the causes of these forms of bias helps enhance scientific knowledge.

Like any human activity, science has always been filled with politics—with backbiting, jealousy, and petty gambits. Any look at the politics of science wouldn't be complete without examples of those. But the twentieth century provides the best (i.e., the most appalling) historical examples of how the sweep of empires can also warp science. Politics marred the careers of probably the two greatest women scientists ever, and even purely scientific efforts to rework the periodic table opened rifts between chemists and physicists.

Related Characters: Sam Kean (speaker), Marie Curie (née Skłodowska), Pierre Curie

Related Themes:

Related Symbols:

Page Number: 205

Explanation and Analysis

After reflecting on how science is inherently flawed because it is produced by humans, Kean has given a brief account of the life of Marie Curie, born Marie Skłodowska in Warsaw in 1867. Marie moved to Paris due to the limited educational opportunities available for women in her home city. There, she achieved extraordinary success alongside her husband and fellow scientist, Pierre, with whom she was jointly awarded the 1903 Nobel Prize in Physics. Despite this success, however, Marie's career was significantly thwarted by the fact that she was a refugee working against a backdrop of imperialism, global tension, sexism, and other social problems.

In this passage, Kean emphasizes that science can never be divorced from politics. Crucially, he identifies two forms of politics: interpersonal politics (which involve mundane social phenomena such as pettiness, jealousy, and egotism) and large-scale (inter)national politics. While the former may be inescapable—flaws such as jealousy and ego are, after all, fundamental parts of being human—the latter warrants more scrutiny. Some might argue that global politics will inevitably end up thwarting scientific progress to some degree. Yet while this may be true, it is also up to humanity how much politics is permitted to obstruct the common good of producing scientific knowledge. At certain points, politics (and particularly patriotism and war) have been prioritized over the pursuit of science, to the detriment of innovation that would benefit humanity as a whole. Yet it doesn't necessarily have to be this way—Kean suggests that it may be possible to work toward a world in which larger-scale politics is prevented from obstructing science as much as possible.

The committee could have rectified this in 1946 or later, of course, after the historical record made Meitner's contributions clear. Even architects of the Manhattan Project admitted how much they owed her. But the Nobel committee, famous for that *Time* magazine once called its "old-maid peevishness," is not prone to admit mistakes.

Related Characters: Sam Kean (speaker), Otto Hahn, Lise Meitner

Related Themes:

Related Symbols:

Page Number: 220

Explanation and Analysis

Lise Meitner was an Austrian physicist of Jewish descent who had an incredibly close working relationship with a German chemist named Otto Hahn. After Meitner was forced to flee the Nazi regime, she and Hahn still met covertly when they could. During one of these meetings, they realized that the new elements Enrico Fermi had supposedly discovered were not new elements at all, but actually the products of nuclear fission. Even though it was Meitner who made this realization—and who had done much of the work in her and Hahn's collaboration—when the Nobel Prize committee awarded a prize to Hahn alone in 1945, he didn't correct them. In this passage, Kean examines how the Nobel committee stuck by their oversight even after it became obvious that Meitner deserved (at least) half the credit.

This quotation explores how institutions like the Nobel can entrench existing problems of sexism, antisemitism, and other forms of prejudice and discrimination that blight the scientific community. The Nobel may not have actively ruled out Meitner because she was a woman or of Jewish descent—but by not taking steps to rectify their initial mistake, they committed a grave historical injustice.

Chapter 13: Elements as Money Quotes

At his death in 1914, he owned Alcoa shares worth $30 million (around $650 million today). And thanks to Hall, aluminium became the utterly blasé metal we all know, the basis for pop cans and pinging Little League bats and airplane bodies. (A little anachronistically, it still sits atop the Washington Monument, too.) I suppose it depends on your taste and temperament whether you think aluminium was better of as the world's most precious or most productive metal.

Related Characters: Sam Kean (speaker), Charles Hall

Related Themes:

Page Number: 237

Explanation and Analysis

After discovering the various ways in which elements have been used as currency, Kean tells the story of Charles Hall, a scientist who, at only 23, discovered a way to separate aluminum from oxygen. This was revolutionary, as previously, pure aluminum was extremely rare. Hall's discovery allowed him to mass market aluminum, earning him a fortune. In this passage, Kean discusses the contrast between aluminum's previously rare status and its sudden ubiquity in everything from food packaging to airplanes. His words illustrate how an element's "value" is culturally constructed and somewhat arbitrary.

Before Hall managed to separate it from oxygen, pure aluminum was rare and therefore precious. Once it began to be used everywhere, it no longer had value as a rare metal but instead had value produced by the sheer vastness of its use. This shows how humans impose value on elements in totally different ways: for instance, gold and diamonds (which are made from crushed carbon) are valuable in large part because they are rare and therefore denote elite status. Yet aluminum is valuable in the opposite sense—it is treasured because it is of so much use to so many people.

Chapter 14: Artistic Elements Quotes

As science grew more sophisticated throughout its history, it grew correspondingly expensive, and money, big money, began to dictate if, when, and how science got done.

Related Characters: Sam Kean (speaker), Charles Hall

Related Themes:

Related Symbols:

Page Number: 238

Explanation and Analysis

The previous chapter examined the periodic table's relation to money, examining how different elements have been used as currency (both real and counterfeit) throughout history. The chapter ends with a discussion of Charles Hall, an American chemist who made fortune by discovering how to separate aluminum from oxygen such that it could be sold as a product. The opening of this chapter considers the relationship between science and money from a different perspective. The incredible advancements in science and technology that happened over the course of the 19th and 20th centuries were wonderful from the perspective of human progress. However, they also had the effect of making science less accessible to all.

In some ways, this contradicts another trend Kean examines in the novel, which is the expansion of Western science to include those who it has traditionally excluded—namely, women and people of color. In this light, science became more democratic and accessible over the course of the 20th century. However, the quotation here provides an important counter to this view: the heightened expense of actually performing scientific experiments meant that it was becoming *less* accessible, even as some of the old social barriers were coming down. Moreover, wealthy institutions and individuals had increasing influence over science, to the point that it sometimes shaped what knowledge was being produced.

Chapter 15: An Element of Madness Quotes

Unlike Crookes, or the megalodon hunters, or Pons and Fleischmann, Röntgen labored heroically to fit his findings in with known physics. He didn't want to be revolutionary.

Related Characters: Sam Kean (speaker), William Crookes, Martin Fleischmann, B. Stanley Pons, Wilhelm Röntgen

Related Themes:

Page Number: 271

Explanation and Analysis

Kean has told the story of two scientists, B. Stanley Pons and Martin Fleischmann, who were famously disgraced for fudging their data and falsely claiming they discovered cold fusion. He then compares this story to Wilhelm Röntgen, the scientist who accidentally discovered X-ray imaging. Kean argues that Röntgen was the opposite of Pons and Fleischmann, who intentionally misreported their results in order to make themselves look like scientific heroes who had discovered a new phenomenon. Röntgen, on the other hand, initially thought he'd gone mad when he appeared to have found a way to see the bones through his skin.

Kean argues that Röntgen's approach of doubting his own instincts (to the point that he chooses to believe that he's gone insane) is what makes him a good scientist. While of course it is understandable that many scientists dream of making a major discovery, this dream may end up clouding one's judgment (as occurred in the case of Pons and Fleischmann). Throughout the book, Kean emphasizes that the likelihood of actually discovering a new phenomenon is very low. It is far more likely that there is another explanation and thus scientists must remain skeptical about their own assumptions of discovery. The desire not to "be revolutionary" is thus one of the marks of being a great scientist.

Chapter 16: Chemistry Way, Way Below Zero Quotes

❝❝ The story starts in the early 1920s when Satyendra Nath Bose, a chubby, bespectacled Indian physicist, made an error while working through some quantum mechanics equations during a lecture [...] Unaware of his mistake at first, he'd worked everything out, only to find that the "wrong" answers produced by his mistake agreed very well with experiments on the properties of photons—much better than the "correct" theory.

Related Characters: Sam Kean (speaker), Albert Einstein, Satyendra Nath Bose

Related Themes:

Page Number: 291

Explanation and Analysis

Kean has provided a rough sketch of some basic principles of quantum mechanics and explained how much this branch of science relates to Einstein's revelation that light behaves like both a particle and a wave. Kean points out that on a very fundamental, mysterious, quantum level, all matter also behaves like a wave to some degree. This quotation is the beginning of the next story Kean tells, which—as his words indicate—will be another tale of how mistakes can advance scientific knowledge.

Crucially, the mistaken calculation depicted here shows how scientific innovation sometimes requires mixing different methods in unexpected ways. In the context of whatever Bose was trying to explain or work out in the lecture, his calculation error was just a mistake. Yet combined with the results of experiments on the properties of photons, Bose realized that this "mistake" might actually contain something valuable. Again, this strange coincidence shows how carelessness and error—while largely undesirable in science—can sometimes produce extraordinary moments of insight.

❝❝ So as physicists have done throughout history, Bose decided to pretend that his error was the truth, admit that he didn't know why, and write a paper. His seeming mistake, plus his obscurity as an Indian, led every established scientific journal in Europe to reject it. Undaunted, Bose sent his paper directly to Albert Einstein. Einstein studied it closely and determined that Bose's answer was clever—it basically said that certain particles, like photons, could collapse on top of each other until they were indistinguishable. Einstein cleaned the paper up a little, translated it into German, and then expanded Bose's work into another, separate paper that covered not just photons but whole atoms. Using his celebrity pull, Einstein had both papers published jointly.

Related Characters: Sam Kean (speaker), Albert Einstein, Satyendra Nath Bose

Related Themes:

Page Number: 291

Explanation and Analysis

Although this quotation begins with a short meditation on the nature of mistakes and surprises and how these can be incorporated as vital parts of the scientific process, its main focus is actually how politics affects scientific research. Again, politics here refers both to a serious, global set of relations and the mundane, petty terrain of emotions. Despite the fact that Bose made a major discovery that impressed and persuaded Einstein himself, no one would publish him. Of course, the accidental nature of his experiment certainly had something to do with this. Yet the fact that Bose was Indian is arguably underplayed by Kean as a factor in why he couldn't get published.

Overall, Kean doesn't devote much time to the impact of racism on science, aside from mentioning the many European Jewish people whose research was obstructed or maligned due to the Holocaust. Furthermore, he never really mentions non-Western forms of science. In reality, the world beyond Europe and North America has made enormous contributions to scientific understanding, even if this is not always legible from a Western perspective. Furthermore, racism was a hugely decisive factor in hindering many great scientists from even being able to find work at all, let alone publish and receive credit for their results. Einstein—himself a German Jewish man who escaped the Holocaust—was also a committed anti-racist. He knew that he would have to make Bose's work legible and acceptable according to the conservative and racist frameworks of the scientific world of his day in order for it to be accepted. He did so, thereby propelling Bose to fame.

Chapter 17: Spheres of Splendor: The Science of Bubbles Quotes

Not every breakthrough in periodic-table science has to delve into exotic and intricate states of matter like the BEC. Everyday liquids, solids, and gases still yield secrets now and then, if fortune and the scientific muses collude in the right way. According to legend, as a matter of fact, one of the most important pieces of scientific equipment in history was invented not only *over* a glass of beer but *by* a glass of beer.

Related Characters: Sam Kean (speaker), Albert Einstein, Satyendra Nath Bose

Related Themes:

Related Symbols:

Page Number: 295

Explanation and Analysis

In the previous chapter, Kean showed how Satyendra Nath Bose and Albert Einstein collaborated to argue that at extremely low temperatures, "supersolid" elements could actually collapse into each other and form what came to be known as Bose-Einstein condensates. It was only years after that the technology to actually test and prove this became available and it can still only be done under very rare, extreme circumstances. In this quotation, which opens the next chapter, Kean switches from the most extreme to the most mundane side of scientific research. Whereas Bose and Einstein's work on coherence applied to states of matter that no human would ever experience in an average day, this chapter opens on a profoundly everyday object: a glass of beer.

This reference to the mundane, ordinary side of life—particularly in contrast to the dramatic temperatures and mind-blowing possibilities of quantum mechanics discussed in the last chapter—serves as an important reminder that the periodic table is relevant to absolutely every part of existence. From the most bizarre, mysterious parts of the universe (such as black holes and supernovae) to food, breathing, and beer bubbles, the elements are literally everywhere. This may inspire the reader by reminding them that they are connected to the most distant parts of the universe and that the scientific laws of the physical world are as much at play during their day-to-day routine as during the Big Bang.

Chapter 18: Tools of Ridiculous Precision Quotes

To scientists who work at standards bureaus, measurement isn't just a practice that makes science possible; it's a science in itself. Progress in any number of field, from post-Einsteinian cosmology to the astrobiological hunt for life on other plants, depends on our ability to make ever finer measurements based on ever smaller scraps of information.

Related Characters: Sam Kean (speaker)

Related Themes:

Page Number: 314

Explanation and Analysis

Kean asks the reader to imagine the most fanatically precise, "anal-retentive" person they can, then multiply that in order to get an understanding of the kind of person who works at a national standards bureaus. At these bureaus—which exist in most countries—employees produce startlingly exact standards and measurements that enhance the safety, accuracy, and effectiveness of scientific practice. In this quotation, Kean considers how standards bureaus enable the work of a huge range of other scientific fields. He also notes how establishing standards and measurements, while perhaps not of huge interest to the general population, is "a science itself" to those who work in this field. This phrase indicates that even aside from what standards bureaus make possible for scientific research at large, they have an inherent importance and value in and of themselves.

This quotation reminds the reader that measurements such as "one second" are not natural, but artificial categories humanity imposes on the world. It is therefore up to humanity to make these measurements as accurate as possible, meaning that they fit the entities they describe to the best possible degree. The quotation also raises the question of why the process of making standards is ever-evolving rather than something that just occurs once. In everyday life, most people probably do not stop to question how long a second *really* is, let alone imagine that this amount could change over time. However, as technology to measure different entities becomes more and more advanced, a second can be measured with greater accuracy.

Chapter 19: Above (and Beyond) the Periodic Table Quotes

I wish very much that I could donate $1,000 to some nonprofit group to support tinkering with wild new periodic tables based on whatever organizing principles people can imagine. The current periodic table has served us well so far, but reenvisioning and recreating it is important for humans (some of us, at least). Moreover, if aliens ever do descend, I want them to be impressed with our ingenuity. And maybe, just maybe, for them to see some shape they recognize among our own collection.

Related Characters: Sam Kean (speaker)

Related Themes:

Related Symbols:

Page Number: 345

Explanation and Analysis

In the final chapter of the book, Kean discusses future directions for the periodic table. He notes that the final element in the periodic table will be 137. Yet this doesn't mean that if or when 137 is found, the periodic table will be "fixed and frozen" for good. Indeed, there are all kinds of different directions in which it could be taken. In this quotation, Kean expresses a desire for scientists to get a little more imaginative with the organizing structure of the periodic table. While the framework that exists right now clearly works, it is not the only option.

This provides a good reminder of how the periodic table is both a natural reality *and* a human invention. It is "true" to some degree, but it is also only one of many possible ways of representing this truth. If this is confusing for readers, Kean's reference to aliens may prove helpful. Kean posits that aliens are likely to have a completely different way of perceiving and representing the world to humans. While they may have discovered the elements just as humans have, their method of describing, organizing, and communicating about these elements is almost guaranteed to be unrecognizable to humans even though we share the same reality. Therefore, it should also be possible for human scientists to revise or reinvent the periodic table in more creative and unfamiliar ways.

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

As a child, Kean has a habit of talking with his mouth full. This leads him to open his mouth while he has a mercury thermometer inside, which subsequently falls out and smashes on the floor, releasing the silver bubbles of liquid mercury inside. Sometimes, Kean's mother lets him poke the little balls of mercury, which medieval alchemists believed was "the most potent and poetic substance in the universe." In contrast to other substances like air and water, mercury is an element. Kean develops a fascination with it, searching for information about it wherever he can.

Kean's story introduces the reason why he was personally drawn to write a book about the periodic table—he's clearly had scientific curiosity from a young age. Yet this passage also conveys another important message: elements are all around us, even in the most mundane situations (such as being ill at home).

In the course of this search, Kean learns that in the 18th century, doctors would prescribe mercury laxatives as treatment for pretty much any illness. (The result was that many people were poisoned to death who might otherwise have gotten better and survived.) However, this use of mercury has allowed archeologists to find campsites of settlers by searching for mercury deposits. Kean also learns about mercury in science class, although at first he can't find it on **the periodic table** due to its name, Hg, which comes from the Latin *hydragyrum*, which means "water silver."

By recalling his own struggles to find mercury on the periodic table—and pointing out that the periodic table isn't necessarily easy for someone with no expertise to understand—Kean demystifies the table, inviting the reader to not feel intimidated by it.

Kean's fascination with mercury leads him through the fields of "history, etymology, alchemy, mythology, literature, poison forensics, and psychology." In college he majors in physics yet he always enjoys scientific narrative far more than conducting experiments in a lab. He becomes fixated with the stories about the elements in **the periodic table**. At first glance, the table is simply an account of all the kinds of matter that exist in the universe. The shape of the table groups different kinds of matter together and there is also information within the table about where the elements come from, how they behave, and how stable they are. The table is also a "human artifact" that tells the story of the history of humanity. It surrounds us even if we don't notice it.

Kean makes it clear that he intends to emphasize the human aspect of the periodic table in this book. This is certainly not the only way one could approach the table; it would be possible to write a version of The Disappearing Spoon *that barely mentioned humanity at all, instead focusing on the straightforwardly scientific information about the elements. However, Kean's book is more of a cultural history of the periodic table than a strictly scientific account, which again makes it more approachable and personable to readers who lack scientific expertise.*

CHAPTER 1: GEOGRAPHY IS DESTINY

Most people have seen a copy of **the periodic table** hanging in their high school chemistry classroom. The table gives off the impression of being highly organized but it's not easy for the average person to understand. If one takes away all the letters and numbers from the table and just look at its shape, it somewhat resembles an asymmetrical "castle." Each "brick" in the castle (or box on the table) is an element. There are a currently 112 known elements, plus a few that are waiting to be confirmed as such. Every element is necessary for the whole rest of the table to function.

Comparing the periodic table to a castle emphasizes the man-made nature of the periodic table. Of course, it also brings up ideas about the symmetry and majesty of the physical universe. While humans might fancy themselves architects of beautiful and ideal structures, in reality these are dwarfed by what can be found in the natural world.

Seventy-five percent of elements in the table are metals. On the righthand side are gases and two elements, mercury and bromine, which are liquid at the normal temperature in which humans live. In between metals and gases lie elements that have complicated and fascinating properties. The location of each element on the table determines its properties, which is why, for elements, "geography is destiny." Column 18 on the far right of the table contains the noble gases. These would probably have been the preferred elements of the Ancient Greek philosopher Plato (if he knew what elements were). Plato developed a theory of "forms," which means the abstract ideal of anything in the universe (e.g., a tree, a fish, a cup). He believed they existed in a separate realm from the mortal world.

Because The Disappearing Spoon *is a book about the history of science, one of the questions Kean investigates is the extent to which ideas previously held about the natural world—particularly in the premodern period—have any intellectual value today. Here, Kean suggests that—although Plato had no sense of what atoms or elements were—there is something about his theory of the forms that prefigured the periodic table, albeit in a more poetic than scientifically accurate manner.*

In 1911, a Dutch-German scientist discovered that below −425°F, helium became an ideal conductor for electricity. In 1937, a team of Russian and Canadian scientists performed a similar experiment and found that at −456°F, helium achieves "perfect fluidness." Plato could never have dreamed of a property like this, which achieves fluidity in such an ideal fashion. An element is a building block—something that cannot be further broken down by any ordinary chemical process. It took until the beginning of the 19th century for scientists to realize this and to begin to really understand elements.

Kean fairly frequently transposes technical scientific concepts into more poetic, emotional language. Of course, what Plato meant by "perfect" is not exactly the same as an element that moves with zero friction. However, by using this more lyrical, often slightly metaphorical language, Kean makes science accessible (even if it is not entirely, technically accurate).

The reason why elements react the way they do is because of electrons, which are negative particles that are contained inside an atom. Atoms exist on different energy levels based on how many electrons they have. They also have positive particles called protons. When electrons are passed between atoms, the atoms become charged and are called ions. Atoms need to achieve the right level of electrons; some will exchange electrons with other atoms "diplomatically," whereas others are more aggressive. Helium only has two electrons and so it only ever exists at one level. Like all other gases, helium atoms don't react with others because they don't need to. They will only react with others under extreme, unusual conditions.

Again, the use of words like "diplomatically" is a way in which Kean uses figurative language in order to help the reader understand the elements. In this case, he personifies the atoms in order to make them seem more human and emotional. Of course, atoms cannot really behave in a "diplomatic" fashion, nor can they be violent. They don't inhabit a social word and they don't have feelings, intentions, and forms of communication like humans do. However, by putting atoms' behavior in human terms, Kean makes it easier for people to connect with, understand, and remember the process he's describing.

Elsewhere on **the table** is the column of the *most* reactive gases, the halogens. More violent still are the alkali metals, which "can spontaneously combust in air or water." They often make compounds with halogens. Electrons are very small compared to protons and neutrons but they take up the vast majority of the space of the atom, whereas the protons and neutrons are nestled in the middle. Halogens and alkalis connect when their ions bond, forming substances like salt—also known as sodium chloride.

Just in case the reader is starting to get lost or intimidated by Kean's abstract descriptions of atoms here, he brings the conversation back to a more immediately recognizable place by mentioning a compound with which everyone is familiar: salt.

The scientist Gilbert Lewis, who studied chemistry in Massachusetts and Germany around the beginning of the 20th century, did much to show how electrons work. He moved to the colonized Philippines to work for the U.S. government before returning to the U.S. and establishing what would come the best chemistry department in the world at UC Berkeley. He was nominated for the Nobel Prize many times but he never won. Part of the problem was that Lewis worked across a vast variety of contexts rather than focusing intensely on one particular question. He revised the definition of acids as "proton donors," instead arguing that they are actually "electron thie[ves]." Today, chemists still use his ideas in order to make stronger and stronger acids.

This passage introduces two of the most important institutions in the book: the UC Berkeley chemistry department and the Nobel Prize. Both of these represent esteem, prestige, and the most transformative branches of scientific research. Yet Lewis's loss shows that these institutions are not necessarily always flawless judges of merit, either. Indeed, they make mistakes based on arbitrary biases, an important idea throughout the book.

Many of these acids are based on antimony, an element that has been used as paint, makeup, a laxative, and other forms of medicine despite the fact that it is toxic. In the 1970s, scientists realized that antimony could be used to make "custom acids." Paradoxically, the strongest acid in the world, carborane, is also the "gentlest." Because it is so stable, it isn't reactive and doesn't burn through matter like other strong acids.

Many of the elements perform in a logical, predictable fashion based on their position on the periodic table and their relation to other elements. However, despite the fact that elements can behave in ways that initially seems unexpected or contradictory to human eyes, this doesn't mean that they are defying logic.

As for Lewis, he was upset not to be recruited to work on **the Manhattan Project** during World War II and he died from a heart attack alone in his lab in 1946. This may have been caused by his cigar smoking. Yet it's also possible that he either accidentally or deliberately exposed himself to cyanide gas, perhaps due to jealousy and resentment of a younger, more successful colleague.

This kind of dramatic and very human story not only draws the reader in—it serves as a reminder that the periodic table and the people that surround it are anything but dull.

The middle of the periodic table contains the transition metals, which are relatively heavy and aggressive atoms. Moving rightward across the table, each element has one more electron than the one to the left. They fill the s-shells and p-shells in order, with s-shells holding two electrons and p-shells holding six. However, things get more complicated with the transition metals. Here electrons start filling d-shells, which hold up to 10 and are shaped like "misshapen balloon animals." Even more confusingly, d-shells are not on the outer layer of the atom, meaning that the extra electrons are concealed beneath other layers and thus not available for reactions. For this reason, the transition metals tend to act similarly, regardless of how many electrons they have relative to one another.

This is another example of the elements behaving in logical, predictable way up to a point, before suddenly beginning to defy expectations. However, while sudden deviations from what seems logical and predictable might be confusing, it rarely means that the universe is actually behaving in a nonsensical manner. Rather, it's usually because humans do not yet understand the actual logical pattern at play.

The two rows detached from the main part of the periodic table at the bottom contain the lanthanides, which are also known as "rare earths." They hide their electrons even further inside the atom, in f-shells, and are hard to differentiate from one another because they behave in such similar fashions. Pure versions of these elements do not exist in the natural world since they always cross-contaminate with one another. 99 percent of an atom's mass is contained in the nucleus. Maria Goeppert-Mayer, perhaps the "most unlikely Nobel laureate ever," researched the nucleus extensively. Goeppert-Mayer was born into a family of German academics but she struggled to get a PhD place and then a job due to sexism.

Research into the elements is both observational and theoretical: some elements are easy to find on Earth, so studying them is as easy as gathering samples and analyzing them in a lab. Other elements, however, do not on exist in forms that are easy to capture. Many of these elements have been "discovered" by being produced in a lab. In these cases, the theory of the element preceded actual observation of the element.

Goeppert-Mayer ended up working alongside her husband, Joseph Mayer, an American chemist. Goeppert-Mayer was invited to participate in the Manhattan Project but—as in the rest of her career thus far—she was only given a minor, auxiliary role. This was when she started her research on the nucleus. The number of protons inside the nucleus—the atomic number—determines which element an atom is. This number plus the number of neutrons is known as the atomic weight. Goeppert-Mayer began investigating the question of why the third simplest element, lithium, is not the third most abundant element in the universe, while the first and second simplest (hydrogen and helium) are the first and second most common.

One of the major motifs of the book is the difficulty that talented female scientists have faced in order to even be allowed to work. For much of history, Western science was a strictly male domain, and female participation was limited—beginning with limitations placed on women even receiving an education in the first place. As a result, many female scientists used the same tactic as Maria Goeppert-Mayer of working alongside their husbands.

Goeppert-Mayer was interested in why the actual third most abundant element in the universe, oxygen, is so exceptionally stable. She managed to prove that nuclei have shells like electrons and also that certain atomic numbers have what she called "magic nuclei" that are extra stable due to their symmetrical spherical shape. Meanwhile, atoms that have "misshapen" nuclei rarely form because their nuclei are too unstable. Around the same time, a group of German scientists made the same discovery about nuclear shells independently of Goeppert-Mayer. However, they acknowledged her findings and invited her to collaborate. This bolstered her career, and she was given a faculty position at UC San Diego shortly after. Still, when she won the Nobel Prize in 1963 her local newspaper described her as a "mother" rather than a scientist.

The fact that Goeppert-Mayer made such an important, paradigm-shifting discovery indicates how much has been lost through restricting people's access to science based on sexism, racism, and other forms of prejudice. If science had been more democratic in the first place, there's no telling what contributions those excluded by the system could have made; scientific knowledge would be much more advanced than it is today.

Reading **the periodic table** horizontally reveals much about the elements, but this is not the only way to read it. Indeed, further information can be gleaned from reading its columns, which tell "whole new stories."

Kean's emphasis on "reading" and "stories" further conveys the idea that the periodic table is a collection of narratives as much as it is a scientific chart.

CHAPTER 2: NEW TWINS AND BLACK SHEEP: THE GENEALOGY OF ELEMENTS

The longest word to ever appear in an English-language document is from a 1964 reference book called *Chemical Abstracts*. It is 1,185 letters long and describes a protein on the tobacco mosaic virus, which was the first virus ever discovered. The word for the protein is so long because each part of it describes a part of the protein. Proteins are made up of strings of amino acids which are themselves made from the most "versatile" element, carbon. The reason why amino acids chain together is due to the fact that they are made up of carbon, nitrogen, and oxygen. A carbon atom will share its electrons with up to four other atoms, making stable bonds. Nitrogen similarly shares electrons, and bonding between nitrogen and carbon takes place in an amino acid.

This passage provides a good example of Kean using something from human culture (a long word made up of many short parts) in order to aid understanding of something from the natural world (proteins). Of course, there are limits to this type of metaphor, which doesn't tend to be very precise. However, as long as the reader takes it as a general idea rather than a direct translation, it will likely help them to remember what proteins are and how they basically work.

Scientists eventually became able to identify extremely long sequences of amino acids, such that the practice of naming proteins after the amino acids they contain had to be abandoned. Reading **the periodic table** vertically, one can see that carbon is more similar to the element below it, silicon, than the elements next to it. Whereas all the lifeforms known to humans are carbon-based, science-fiction creators have dreamed that there may be silicon-based life somewhere in the universe. There are, however, important differences between carbon and silicon: for example, while human lungs successfully process carbon dioxide, inhaling silicon dioxide (from which sand and glass are primarily comprised) is dangerous for human health.

This is one of the most exciting sides of science, where knowledge about the fundamental building blocks of the universe meets speculation about wild possibilities like alien life. Here, Kean shows how grounding speculation in what is known about the universe both inspires and limits the kinds of distant, fantastical scenarios humans can imagine.

Some argue that silicon-based life is plausible because some earth animals, such as sea urchins, have silicon in their bodies. However, in order for silicon-based life to exist, these alien life-forms would have to be able to draw silicon in and out of their bodies in the same way carbon-based life-forms do with carbon. Yet while carbon dioxide exists as a gas at Earth temperatures, allowing life-forms to breathe it in, silicon dioxide doesn't become a gas until 4,000°F. Anywhere one might expect life to exist, it would be a solid. Silicon-based life thus wouldn't be able to breathe. Furthermore, such life-forms would have no use for blood, and silicon doesn't dissolve in water.

In response to this passage, it might be tempting to argue for the existence of silicon life-forms which somehow have the ability to "breathe" solid silicon. Just because such a process would be totally foreign and inexplicable to humans doesn't mean it cannot exist. At the same time, scientists must base their speculation about the universe on what is already known even while they acknowledge the limits of this information.

Overall, no one can definitively rule out the existence of silicon-based life, but based on the available information it seems highly unlikely. Yet that doesn't mean silicon is unimportant. The column that contains silicon and carbon also contains germanium, tin, and lead. Germanium is the "black sheep" of this group. After failed attempts to build a silicon amplifier, John Bardeen and Walter Brattain built a germanium amplifier in 1947, which they called the "transistor." William Shockley, an electrical engineer and physicist who'd attempted to build the silicon amplifier, tried to "steal credit" for their work. (Later in life, he went on to become a eugenicist.)

Here Kean shifts from the unknown possibilities of alien life to a much more practical, everyday matter: electrical engineering. An amplifier is a piece of electronic equipment that increases the power of a signal. It is a foundational component of electronic technology and thus finding the best element through which to construct it was a vital—and lucrative—task.

Shockley managed to convince people that he did indeed play a key role in the development of the germanium amplifier. However, as electrical technology developed, engineers began to wonder if silicon would actually be a better element to use in making transistors after all. Bardeen, Brattain, *and* Shockley all won the Nobel Prize in Physics in 1956. Yet the transistor industry was at the time in need of major change. Jack Kilby, an electrical engineer from Kansas, was hired by Texas Instruments in 1958. There, the computer hardware required an enormous number of cheap and dysfunctional silicon transistors. While the other employees were on vacation, Kilby experimented with building his own invention: an integrated circuit.

This passage depicts a particular (and rather amusing) trope of scientific innovation. While some people can get caught up focusing one problem (e.g., whether geranium or silicon is the better element to use for transistors), someone else might find a solution by abandoning the initial framework and focusing on a different answer altogether (e.g., building an integrator circuit to use instead of transistors).

Unlike with the use of multiple silicon transistors, the integrated circuit didn't have to be soldered (and re-soldered) together. Kilby never received proper credit for his invention, which instead went to "one of Shockley's proteges." Yet over time his achievement gradually became acknowledged and in 2000 he finally won the Nobel. However, although the first integrated circuit was made from germanium, engineers soon switched to silicon due to its cheapness and abundance. Like many elements, germanium was left "anonymous." Only a few have reached silicon's level of fame.

Here, Kean draws an analogy between the fame of scientists (measured by things such as winning the Nobel) and the fame of elements (measured by use in important products). There is a sense in which this analogy is a little silly, as elements are inanimate and therefore don't care whether they are famous to humans. However, it makes for an entertaining and memorable way to tell the story of germanium in human culture.

CHAPTER 3: THE GALÁPAGOS OF THE PERIODIC TABLE

Kean proposes that "the history of **the periodic table** is the history of the many characters who shaped it." One of these characters is Robert Bunsen, who didn't actually invent the Bunsen burner but instead improved its design. Before that, however, Bunsen had a passionate interest in arsenic: he worked with arsenic-based chemicals that smelled horrific, caused hallucinations, and left black residue on his tongue. Although this led him to develop the best antidote to arsenic toxicity, he still paid the price of his arsenic obsession when a glass beaker in his lab exploded and caused him to lose most of his eyesight.

These stories from the life of Robert Bunsen show how dangerous working with elements can be. At the same time, there is something admirable—if a little alarming—about Bunsen's fearlessness in the face of chemical danger.

At this point, Bunsen developed a fixation with natural explosions and he spent time researching geysers and volcanoes. He then invented the spectroscope, a tool that uses light to examine the elements by heating them and looking at the specific colors of light they produce. After this, he developed a version of the Bunsen burner to use within the spectroscope in order to heat the elements inside. These innovations led to a rapid acquisition of knowledge about the elements. At this point, **the periodic table** did not yet exist. The person credited with developing this organizational framework was Dmitri Mendeleev, although he didn't do it alone.

Kean jumps back and forth in time between before and after the periodic table was invented. While at times this might be a little confusing, it also highlights a sense of continuity between scientific understanding of the elements before and after the invention of the periodic table. This, in turn, shows that the table originally developed by Mendeleev is not the only way to know the elements—other frameworks have been used and might be used again in the future.

Mendeleev was born to a large family in Siberia, and studied in St. Petersburg, Paris, and Heidelberg, where he was briefly the student of Bunsen. He became a professor in St. Petersburg in the 1860s. At this point, several scientists had already proposed tables of elements, and Mendeleev even shared a prize with a German chemist for both separately discovering what was called "periodic law." Bizarrely, later in life, Mendeleev refused to believe in things he couldn't see, including atoms and electrons. Before this point, however, he made enormous contributions to human understanding of the elements, such as the fact that elements are defined by their atomic weight.

Mendeleev is one of several scientists Kean mentions who combined profound insight with strange or objectionable views (recall Shockley and his advocation of eugenics). Some of the scientists who made the most important contributions to the periodic table turned to spiritualism, were deeply or sexist, or—as in Mendeleev's case—ended up refuting basic scientific principles. This serves as a useful reminder that even scientific geniuses are humans and they are thus capable of being highly irrational.

Mendeleev was able to accurately sort what were, at the time, the 62 known elements in the universe, and also had the foresight to realize more elements would be discovered. He was even able to predict the properties of these unknown elements based on the properties of those that were known. Significantly, the discovery of noble gases in the 1890s did not contradict Mendeleev's table, and they could be added without jeopardizing the existing structure. Mendeleev was an extraordinary character: he completed his major achievement in the final hours before a deadline and married a second wife while the tsar turned a blind eye due to his scientific achievements. He was, however, eventually fired due to his anarchist political beliefs.

Another important motif in the book is the way in which science has been continually thwarted by politics throughout human history. Scientists like Mendeleev may have been permitted to have eccentric personalities and even break fundamental social laws. Yet embracing radical anti-authoritarianism was considered one step too far, no matter how great his achievements.

Mendeleev's speculations annoyed Paul Emile François Lecoq de Boisbaudran, who was the scientist to actually *discover* gallium (which Mendeleev had called eka-aluminum)—not just predict that it existed. Gallium melts at 84°F, making it one of the only liquid metals humans can touch. A popular trick is to make spoons out of gallium and watch them "disappear" (in reality, melt) when they come into contact with a cup of tea. After hearing about Lecoq de Boisbaudran's discovery, Mendeleev tried to take credit for it, which in turn led an irritated Lecoq de Boisbaudran to falsely claim that **the periodic table** had actually been invented by a little-known French scientist.

Again, it might be a little confusing what Kean means when he refers to "discovering" or "producing" a new element. As this passage shows, a scientist (like Mendeleev) can predict an element exists, but without being able to prove its existence, they have not actually discovered it. Moreover, discovery doesn't necessarily take the form of finding the element in the wild—it often involves producing it a lab.

Mendeleev then responded by claiming that there was an error in Lecoq de Boisbaudran's data. While at first glance this seemed like brash and baseless speculation, he was actually correct, and Lecoq de Boisbaudran was forced to retract his initial data before publishing a correct version. In this case, a theory proved an experiment wrong, not the other way around. Still, trying to decide whether theories or experiments are more important in driving scientific innovation is a fruitless endeavor, as both are vitally important. Although Mendeleev outlined the initial version of **the periodic table**, this has been subject to much revision over the years. For example, Mendeleev conceded that at the time, little could be known (or predicted) about a group of elements called the lanthanides.

The relationship between theory and experimentation is another important aspect of the book. These two methods of doing science often work together—indeed, scientific inquiry would not be possible without the involvement of both of them—but sometimes they can clash. It is more often the case that experiments prove a theory wrong, but as this passage shows, sometimes it can work the other way around.

Back in 1701, a German teenager named Johann Friedrich Böttger performed a trick of making two silver coins "disappear." King Augustus of Poland arrested Böttger and tried to force him to perform the trick in his castle, which he couldn't do. However, Böttger promised that he *could* make porcelain, which was something of an obsession for the European elite ever since Marco Polo first brought some back from China in the 13th century. Europeans tried to make it themselves with little success. King Augustus had already assigned Ehrenfried Walter von Tschirnhaus to develop a porcelain-making technique, and now he gave Böttger the role of Tschirnhaus's assistant.

Again, this passage provides yet another leap back in time to a point not only prior to the invention of the periodic table, but before the establishment of chemistry as it exists today. In the West, the antecedents of modern chemists were alchemists. While alchemists worked with elements, they didn't necessarily understand them very well and they often relied on magical or superstitious explanations for what they were doing.

Working together, Tschirnhaus and Böttger successfully discovered a porcelain recipe which soon spread across Europe. Mining of feldspar, a key ingredient in making porcelain, took off—including in the Swedish village of Ytterby. The Ytterby quarry, as scientists would soon discover, was filled with lanthanides. In the 18th century, Sweden experienced its own particular age of Enlightenment, leading to a proliferation of scientists including Johan Gadolin, who was born in 1760. While living in Turku (now part of Finland), he imported and studied rocks from the Ytterby quarry. There, he discovered a remarkable six of the 14 lanthanides, all of which he named after Ytterby or Sweden in some way.

Again, while many elements have been found by scientists sitting around making calculations and performing experiments in the laboratory, some have been discovered in a more classic sense, in that they were literally found existing in their natural state.

CHAPTER 4: WHERE ATOMS COME FROM: "WE ARE ALL STAR STUFF"

For a long time, scientists assumed that all the elements that currently exist have always existed. When the Big Bang theory emerged in the 1930s, it was assumed that this was coherent with this idea of the elements always existing. However, scientists then began to realize that young stars contain only two elements, hydrogen and helium, and that only older stars contain an abundant variety of elements. In the 1950s, four scientists proposed that the early universe featured mostly hydrogen, plus a little helium and lithium—and nothing else. Stars produce nothing but helium for billions of years but—at a certain point of burning—then begin fusing helium atoms, which results in a proliferation of further elements.

Though it is hard for the human mind to comprehend, everything in the universe—from the human body to enigmas at the edge of the universe—was once a hydrogen, helium, or lithium atom. It is one of the mysteries of the universe that such extraordinary complexity emerges from the simplest of building blocks.

After using up their stores of helium, some stars die, whereas other, bigger ones keep burning until they reach the final element in **the periodic table**, iron. If a star has produced iron, it won't produce any further elements. This still leaves the very heaviest elements (from cobalt to uranium). Scientists believe that these are produced when gigantic stars implode into tiny iron cores, then explode outward in a gigantic supernova. A supernova happened in our solar system around 4.6 billion years ago, and the dust cloud that formed as a result eventually became our sun and planets. Several elements are named after the planets in our solar system, including uranium, neptunium, and plutonium.

Stars contain so much energy that the reactions taking place in them produces new elements—yet even this level of energy is dwarfed by that produced when a star implodes before becoming a supernova. Again, the fact that the same elements are found on Earth as in stars emphasizes both the vastness of the universe and the interconnectedness of all things.

The way elements behave on gassy giants like Jupiter is so unlike the way they do on Earth, leading scientists to come up with seemingly outlandish speculations about what these planets are like. The weather on Jupiter is similarly extraordinary—there is a hurricane three times the size of Earth that has been raging on the planet for centuries. Scientists use weather maps to explain the placement of elements like helium and neon on Jupiter, which aren't distributed in the way one might immediately expect.

Compared to studying distant galaxies or the Big Bang, it might seem comparatively easy to study planets in our own solar system, like Jupiter. However, Jupiter is still hundreds of millions of miles away from Earth, and the planet's conditions that would make it impossible for any human to go there even if distance wasn't a problem.

The rocky planets (Mercury, Venus, Earth, and Mars) formed after the gas giants. At first, all the elements inside Earth were mixed together in a uniform way. Over time, however, they moved around and ended up deposited in different parts of the planet in "clusters." The relative abundance of certain elements within each solar system is unique, an "elemental signature" determined by the way in which the solar system was originally formed by a supernova. The atomic weight of each element in **the periodic table** is not fixed across the universe—rather, it is true for our galaxy. Scientists know how the earth, solar system, and galaxy were formed by analyzing the elements in the earth's crust.

As if something like atomic weight weren't hard enough to wrap one's head around, it isn't even a universal truth—it's only true for this particular galaxy. This is just one of the book's many reminders about the vastly unknowable nature of the universe.

The age of Earth was precisely worked out in the 1950s by a graduate student named Clair Patterson, who had previously worked on **the Manhattan Project**. He knew that there were three different isotopes (types) of lead on Earth, each with a different atomic weight. Some of this was created by the supernova that formed our solar system, and some came more recently, from uranium. He decided to use the relative abundance of the different isotopes to measure the rate of uranium decay, which would provide an accurate sense of the earth's age. Although Patterson ran into some initial difficulties, he was maniacally devoted to the project and he eventually managed to estimate that the earth is 4.55 billion years old.

Patterson was hardly the first scientist who tried to figure out the age of the planet. However, his method of using the rate of uranium decay (known as radioactive dating) was revolutionary and it allowed him to become the first scientist to achieve a relatively accurate estimate.

In 1977, Luis and Walter Alvarez, physicist-geologists who were also father and son, studied limestone in Italy that dated from the dinosaurs' extinction. They found inexplicable red clay along with unusually high amounts of iridium, which is often found on comets. This led them to speculate that a giant asteroid hit the earth 65 million years ago, killing 99 percent of life on the planet. Soon after, this theory was bolstered when a large crater, likely caused by an asteroid impact, was discovered in Mexico. Yet this theory clashed with evidence that the dinosaurs died out gradually over hundreds of thousands of years. Some argued that many asteroid hits had taken place over the course of Earth's history, each causing the mass extinctions that have happened at fairly regular intervals.

It is one of the paradoxes of science that there is more certainty about something as distant and abstract as the Big Bang than there is about the extinction of the dinosaurs, which happened right here on Earth and was relatively recent. Yet just because something is distant and hard to fathom from a lay perspective doesn't necessarily make it harder for scientists to understand, and vice versa. Indeed, some of the biggest mysteries in science can actually be found within the human body.

However, Earth is small and asteroid impacts are highly unlikely; what could have caused them to happen in a regular pattern? A scientist named Richard Muller proposed an answer: the sun has a twin, another star called Nemesis, that causes asteroids to hurtle toward Earth at regular intervals. Although even Muller only proposed this idea half-seriously, it would explain a lot of the unresolved questions about the extinction of the dinosaurs. Muller published a book about Nemesis, but few took the possibility of its existence seriously. Other explanations for why a semi-regular rain of comets hits Earth include the possibility that they are pulled by the sun itself. The astrophysicist Carl Sagan memorably said, "We are all star stuff," referring to the fact that all the elements on Earth (and in the human body) were originally formed inside stars.

Muller's decision to call the possible twin star "Nemesis" is appropriate. Nemesis is the Ancient Greek goddess of retribution (particularly punishing those guilty of hubris, or excessive pride and arrogance rather than humility before the gods). If another star was impacting our solar system without human knowing, this could certainly be considered a Nemesis-like act of balancing the scales. Yet Nemesis is also an appropriate name due to its origins in Greek mythology. The idea of the star Nemesis certainly has a mythical, poetic quality to it.

CHAPTER 5: ELEMENTS IN TIMES OF WAR

Chemical warfare began in Ancient Greece—yet back then, the gas used by the Spartans against the Athenians was more irritating than dangerous. Chemical weapons were rarely used in the ensuing centuries, and the Hague Convention of 1899 banned the use of them in war. Unfortunately, this didn't actually stop them being used. French forces used bromine weapons at the beginning of World War I, and although these were completely ineffective, they sparked terror across the world. Research on chemical warfare was quickly escalated by a German scientist named Fritz Haber, who devised a process to capture nitrogen from the air and turn it into ammonia, which is the basis of all the fertilizers used in agriculture today.

The knowledge and uses of the elements discussed thus far have largely been either positive or neutral. However, at this point Kean takes a sharp turn to describe one of the most horrific end to which science can be put: chemical warfare. Perhaps what is so disturbing about this field is that it uses years of calculated scientific labor, thought, and innovation in order to make tools that kill people as effectively and brutally as possible.

Unfortunately, Haber was far more interested in chemical weapons than feeding the hungry. His wife, Clara Immerwahr, was also a scientist; she often worked as his assistant but she was appalled by his work on chemical weapons and refused to assist with the bromine project. As with the French efforts, the Germans' initial use of bromine in battle was a failure, such that the British troops against whom it was used didn't even notice the attack. Haber decided to switch to chlorine, a chemical that has horrifying effects on the body: turning a person's skin yellow, green, and black and filling their lungs with water so they die by drowning. This innovation revolutionized chemical warfare. Haber designed a calculation, Haber's Law, which measured the relationship between the concentration of gas, endurance of exposure, and death.

The horrifying story of Fritz Haber will destroy any lingering assumptions that science or scientists are inherently good. While not inherently bad either, the horrifying uses to which science can be put means that at best it is a neutral tool that can easily be abused (to terrible effect).

Immerwahr begged Haber to stop his work on chlorine weapons, but he didn't listen. Immerwahr ended up killing herself, although even this didn't stop Haber. In 1918 he won the Nobel Prize in Chemistry for his work on ammonia fertilizers and the following year he was charged as a war criminal. He tried and failed to join the efforts to pay the enormous reparations imposed on Germany. The Nazi military ultimately used Zyklon A, the insecticide Haber created, to produce Zyklon B, the gas used to murder millions of Jewish people—including family members of Haber, who was a Jewish convert to Lutheranism and who fled to England as a refugee in 1934.

Horrifyingly, there was nothing that could stop Haber's thirst for brutal warfare—not his conscience, not his wife, and not even the fact that to the Nazis, his loyalty and patriotism didn't matter simply because Haber had Jewish heritage. Indeed, it is an especially bitter irony that the Nazi regime used the work of many Jewish scientists in enacting the Holocaust.

As World War II approached, the German military became fixated on a new element: tungsten. Back in World War I, the Germans needed a metal far more durable than iron for their weaponry. They had been using molybdenum but they were concerned about their supply running out. The only known source of molybdenum was a mine in Colorado, and the mining rights belonged to a Nebraskan banker named Otis King. Hoping to seize it for themselves, a mining company in Frankfurt, Germany sent a team of agents, including their "top man," Max Schott, to Colorado. Schott managed to successfully harass King to the point that he sold the rights to Schott for the low sum of $40,000.

This passage highlights yet another way in which the periodic table is intimately intertwined with global politics—through extraction of elements from the earth. This was (and continues to be) one of the driving forces of colonialism, as wealthy countries exploit these resources from less-developed nations. As this passage shows, mining useful elements like tungsten also plays an important role in global conflict.

The U.S. government shut down the transport of molybdenum to Germany as soon as it learned what the Frankfurt mining company was doing, but it was too late—the metal was already on the other side of the Atlantic, being used to construct German weapons. However, by the time World War II arrived, molybdenum was replaced by tungsten as the element of choice for weapons. The source of this tungsten was Portugal, a country that was supposedly neutral but in reality tended to play both sides at once in the war. Portugal's dictator, Antonio Salazar, used his country's monopoly on tungsten to export it at hugely inflated prices. The metal was highly coveted for use in weapons due to its extreme durability and strength.

Again, this shows how a neutral scientific fact—for example, the notable durability and strength of tungsten—can be turned into a highly charged and sinister political issue. It is a mind-boggling but true fact that many people throughout history have become rich and powerful—and have brutally oppressed others—simply by occupying the right proximity to the right elements.

As Germany took as much tungsten as it physically could from Portugal, the Nazi regime paid in gold seized from Jewish citizens. The U.S. encouraged the U.K. to stop Portugal from supplying tungsten to Germany. Finally, in 1944, Portugal put on embargo on selling tungsten to Germany—but at this point the war was coming to an end. Beyond a small handful, most of the metals on **the periodic table** were not put to use until after 1950. Two metals in particular caused trouble in the postwar period: tantalum and niobium. Because they charge well, they are present in most cell phones, and the country with the biggest supply in the world is the Democratic Republic of the Congo.

The scientists who helped discover new elements after 1950 likely could never have anticipated how their discoveries—which were supposed to increase human knowledge and aid progress—would end up inadvertently leading to some of the most brutal bloodshed in history in the Democratic Republic of the Congo.

In 1996, the horrific genocide that took place in Rwanda spilled over to the neighboring Congo. The intense demand for tantalum and niobium was a driving force in the brutal war that ensued. The war technically ended in 2003 although conflict continues. 5 million people have died: a terrible testament to the worst side of human interaction with the period table.

While the proliferation of smart phones is definitely a driving force of the terrible conflict in the Congo, it cannot be blamed alone. Arguably more important is the legacy of Belgium's brutal colonization of the Congo and the way this intersects with ongoing neocolonial capitalism.

CHAPTER 6: COMPLETING THE TABLE…WITH A BANG

Across the history of the universe, some elements have gone "extinct" because they are too unstable to survive. As scientists began to understand this process, they discovered something that was much more powerful than they expected—as well as more dangerous. Before World War I, scientists at the University of Manchester were at work analyzing "every discovered element up to gold." One of them, Henry Moseley, discovered a mathematical relation between an element's atomic number, how many protons it has in its nucleus, and the wavelength of X-rays created when a "beam" of electrons strikes the atom's nucleus. At this point, **the periodic table** was different to the version Mendeleev published in 1869. It had been reorganized, yet uncertainty remained over whether this was the accurate version.

Note that when an atom goes "extinct," this doesn't mean that it disappears. Rather, it turns from one element into a different kind of element. The atom is still there, it just has a different structure and set of behaviors, which means it falls into a different category of matter.

At only 25 years old, Moseley took up his lab director, Ernest Rutherford's, idea that each atom had a compact, positively charged nucleus, something that at the time almost no one believed. Mosely suggested that an element's location on the periodic table was not just determined by its atomic number, but also its (equivalent) nuclear charge—a theory that helped tidy up a lot of unresolved questions about the table. Still, many remained suspicious of his findings. Sadly, Moseley himself met a tragic end as he was killed like so many other young men in World War I. However, his ideas lived on. Scientists scrambled to find the elements that Moseley had identified as missing from the table. By 1940, only one natural element was left to be discovered: element 61.

This passage presents another much more obvious and basic way in which war has obstructed scientific progress: by killing scientists like Mosely, along with millions of other innocent young men who become soldiers (not to mention civilians) during wartime. At the same time, the book will show that this fact sits uneasily with the reality that war is often a period of heightened investment in science, leading to an intensity of scientific advancement.

One of the few teams of scientists trying to find element 61 was led by Emilio Segrè, though they were not successful. In 1949, however, an American team announced that they had found it and that they were going to call it promethium, after the Titan who stole fire and gave it to humanity. However, this didn't rouse much excitement; few people even really paid attention. The reason for this was that everyone's focus was on the atomic bomb.

This passage introduces the single most sinister product of humanity's fascination with the elements: the atomic bomb. One of the negative consequences of the atomic bomb (albeit a comparatively very minor one) was that it absorbed so many resources and so much attention, which might otherwise have gone to other avenues of scientific research and development.

In 1939, Luis Alvarez was a young physicist at UC Berkeley when he learned about the German scientist Otto Hahn's experiments on nuclear fission (splitting a uranium atom). Within seconds, Alvarez attempted to spread this research to everyone he knew. Hahn's research represented a major development in the understanding of how atomic nuclei function. Moseley had shown that isotopes could have the same overall charge yet different atomic weights. Many questions were still unanswered, although the nascent field of quantum mechanics was attempting to address them. At the time, scientists were also begin to understand radioactivity, which is how atoms decay or "fall apart." A major breakthrough came in 1932, when a student of Rutherford's named James Chadwick discovered neutral neurons (which have neither positive nor negative charge).

This was an exhilarating—if terrifying—time in science. Not only was a huge amount of new knowledge about atoms and elements being produced, but there was also a competitive aspect to it, as different sides in World War II were racing to develop nuclear weapons before the others. For scientists, this was stimulating. For humanity at large, it ended up having catastrophic results.

Unfortunately, all of this excitement regarding new understandings of atomic structure was set against the backdrop of the rise of fascism and fall of Europe. Nuclear fission wasn't just a scientific fascination, but the means for creating an atomic bomb. Few people (including many of those working on it) believed that creating such a bomb was actually possible. It was so unlike anything that had been done before that **the Manhattan Project**, which was tasked with working on it, devised a totally new research strategy called the Monte Carlo method.

Again, this passage emphasizes how exciting and important scientific innovation goes hand-in-hand with horrific brutality and destruction. The question of what responsibility the scientists who worked on the Manhattan Project bear is an important and complex one, and Kean doesn't address it directly in the book. (Though he does mention that few believed they would actually succeed in building the bomb.)

One of the big questions facing the scientists involved was how much plutonium and uranium would be needed to make the bomb. Many of the scientists' wives were enlisted to make calculations to figure this out; they were given a new name, "computers." This method was new because it borrowed from both the experimental and theoretical way of doing science without either being one or the other. It was based entirely on calculations, although, fortunately for the project, these calculations were very good. The end result was successful in the sense that two uranium bombs were produced and used in the war—the first dropped on Hiroshima, the second on Nagasaki.

The consequences of the Manhattan Project for scientific progress are hard to overstate. As this passage indicates, the first "computers" (at least in a certain sense) were part of the project. Even more astonishingly, these computers were human women working with pencils and paper. This is an especially remarkable detail considering how women have largely been excluded from the field of computer science.

Once **the Manhattan Project** was over, a Polish scientist named Stanislaw Ulam remained fascinated by the research method of the project. He realized that the Monte Carlo method of conducting "experiments" through trying out a huge number of calculations could prove transformative for science. The Monte Carlo method grew quickly in popularity and it was no longer limited to the particular project of uranium fission. However, it did continue to be used for the development of even more powerful nuclear weapons called "supers." Yet even these were not the worst weapons bomb scientists had come up with. The very worst was the cobalt-60 dirty bomb, which uses gamma radiation rather than simply heat for destruction. Gamma radiation not only kills living things but mangles cells, leading to cancers and deformities.

This passage juxtaposes two scientific innovations that resulted from the Manhattan Project—one positive and one resoundingly negative. On the positive side, the Monte Carlo method became the basis for using computing in scientific research, running millions of calculations at hyper speed in order to advance scientific knowledge. Yet this innovation sits uncomfortably aside the terrifying description of cobalt bombs, which is one of the most horrifying and catastrophically dangerous human inventions of all time.

Cobalt is an especially brutal element in this sense because the radiation it emits is both destructive at the moment of impact *and* continues to have harmful effects for years. The scientist who invented the cobalt bomb, Leo Szilard, hoped that these weapons would never actually be built—and as far as anyone knows, they haven't been. Meanwhile, once the Soviet Union also acquired nuclear bombs, it made an agreement with the U.S. called "Mutually Assured Destruction," or "M.A.D.," which was designed to deter use of nuclear weapons based on the idea that it is impossible to "win" a nuclear war.

Again, this passage raises the question of the extent to which scientists like Leo Szilard should be blamed for the destructive inventions they create. Unlike the bloodthirsty Fritz Haber, Szilard did not actively want to create weapons that would torture and kill people. However, this is what he did. Science itself may be a neutral tool, but this doesn't mean that scientists should get to evade responsibility for their actions.

CHAPTER 7: EXTENDING THE TABLE, EXPANDING THE COLD WAR

In 1950, *The New Yorker* reported that two new elements had been discovered at UC Berkeley, named berkelium and californium. The article teased the scientists in question for this naming choice. However, naming new elements was no joke—it was a serious dimension of the Cold War. Glenn Seaborg was a Nobel Prize-winning Berkeley professor who had been a team leader on **the Manhattan Project** and advised a long list of presidents. However, his first major breakthrough was simply thanks to "dumb luck." In 1940, a colleague of Seaborg named Edwin McMillan created "the first transuranic element," which he called neptunium. Following this, he sought to investigate if element 93 could decay into 94.

Even something as seemingly benign and uncontroversial as giving an element a name took on dramatic political significance under the charged atmosphere for the cold war. On one hand, this stimulated investment in and public appreciation for science, which was arguably a good thing. At the same time, it severed opportunities for global collaboration and turned innocent acts of scientific discovery into acts of (cold) war.

McMillan's research was interrupted when he was conscripted by the U.S. military to work on radars for the war effort. Seaborg was left behind and he succeeded in getting element 93 to decay into 94, which was named plutonium. This discovery propelled Seaborg to fame and shortly after he was called to work on **the Manhattan Project**. He brought a technician with him named Al Ghiorso; after the project was over they returned to Berkeley and together discovered more elements than any other scientist. Although the general population did not display much interest in their discoveries, the pair kept at it. Their crowning achievement was the creation of element 101.

There are several examples in the book of scientists being passed over for opportunities and acclaim, only to use these slights to their advantage. This is what happened to Seaborg, whose relative obscurity meant that he wasn't drafted into military service and used the time he had to instead discover a new element, plutonium.

The process of creating element 101 was extremely tricky. It involved conducting half of the experiment in one lab and the other in another lab that was miles away. Ghiorso had to quickly drive the sample between labs himself. The experiment finally succeeded after many tries in February 1955. The new element was named mendelevium, after Dmitri Mendeleev, which was politically bold in light of the ongoing cold war. Meanwhile, only two elements were discovered in Russia: ruthenium and samarium. In the early decades of the Soviet Union, the government poured a large amount of money into science, hoping to reverse the impression of Russia as a "backward" nation. This attracted the attention and envy of people around the world.

The question of whether capitalism or communism better supports science will, of course, be answered differently depending on who one asks. On one hand, having state support for science can be useful: if the state provides free, high-quality science education to young people as well as funding for universities and other institutions, the result will be progress. Under capitalism, private entities might fill whatever funding gaps the state does not provide. Capitalists would argue that this is a more efficient system.

However, once Joseph Stalin came to power, the flourishing of Russian science faltered. Stalin ruthlessly ruled against what he called "bourgeois" forms of science, and scientific knowledge in the country took a retrograde, irrational turn. Many scientists were arrested and sent to forced labor camps, where they worked on nickel mines. Stalin considered physics "bourgeois" and thus considered forcefully shutting down the whole field—however, he then realized this would jeopardize the Soviet nuclear weapons program. One of the physicists in this program was named Georgy Flyorov, a man who paid close attention to German and American research on uranium fission in the 1940s and tipped Stalin off that these countries were perhaps trying to build a nuclear bomb. The government rewarded Flyorov with the gift of his own research lab.

This passage shows the downsides of having a state-supported funding system for science (and, more importantly, of having a brutally authoritarian government). Many capitalists would argue that trusting the state to fund science education and research risks creating a situation in which the state controls what knowledge is produced (as Stalin did). At the same time, the exact same accusation could be made of the capitalist system. If wealthy companies and individuals fund science, they may well influence the production of knowledge to suit themselves (as has happened in reality).

During the race to create new elements and fill out the periodic table, the Berkeley scientists largely "won." However, Russia did have a triumph in the form of element 104. Seaborg and Ghiorso rushed to make 104 themselves, but by that point, the Russians had already made 105. The opposing teams produced 106 in 1974 at almost the exact same time. The teams would not agree on the names of these new elements, each developing their own respective names for them. The competition lasted into the 1990s, when a West German team also joined in. An international ruling body stepped in to adjudicate, ultimately awarding the naming rights to the Berkeley scientists. However, by the 1990s, the Berkeley team fell far behind the Germans and Russians.

This passage underlines how international competition can be both good and bad for science. Competition drives science forward, inspiring scientists and making it more likely that their work will be funded (by a government or other body invested in the outcome of the competition). At the same time, it imbues science with unpleasant qualities of egotism, jealousy, and pettiness—and prohibits collaboration.

Berkeley's "comeback" came in the form of a daring experiment that resulted in the production of not one but *two* new elements: 116 and 118. Yet when the Russians and Germans tried to repeat the experiment, they did not get the same results: a member of the Berkley team, Victor Ninov, had faked the data, inputting false positives. Ninov was fired and Berkeley was forced to take back their claim to have found 118. To make matters worse for Berkeley, the Russians have now found 118, and while at the time of writing official approval is still pending, Kean has no doubt that it will pass.

The Disappearing Spoon *features a surprising number of scientists who tinker with (or even entirely fake) their results. The reasons for this are many: some seek money or fame, while others appear to delude themselves that they are doing nothing wrong in the process of deceiving others. The intensely competitive and pressurized life of a high-level scientist can be intense, leading to regrettable behaviors.*

CHAPTER 8: FROM PHYSICS TO BIOLOGY

In 1960, *Time* magazine listed 15 scientists as part of its "Men of the Year." One of these men was Emilio Segrè, a Jewish immigrant who escaped World War II. Another was Linus Pauling, who had tried to go to Berkeley for graduate school, but—after his letter to Gilbert Lewis enquiring about admission as lost—ended up at Cal Tech instead. Meanwhile, Segrè was given a job at Berkeley, but on humiliatingly low pay. Pauling and Segrè are "two of the greatest scientists most lay people have never heard of," who are united by making enormous, career-defining mistakes. While accidents and mistakes have often played an important role in scientific progress, "Pauling's and Segrè's were not those kinds of mistakes."

In this passage, Kean makes a striking point—that a person can be one of the greatest scientists in history and still make a profound, career-defining mistake. Again, this serves as a useful reminder that scientists are human and thus inevitably flawed. Even the greatest scientific geniuses make mistakes—sometimes huge and disastrous ones.

People have claimed to have discovered element 43 many times; it is as elusive as the Loch Ness monster. In 1828, 1846, 1847, and 1869, people claimed that they had found it, only to be proven wrong. In 1909, a Japanese scientists once again claimed to have found it when actually he had found another new element, 75, although this wasn't actually revealed until 2004, after his death. The same German scientists who consciously found 75 in 1925 also claimed to find 43 in 1925, but they were also wrong. In 1937, however, Emilio Segrè and another Italian, Carlo Perrier, finally made a plausible claim to have found 43.

The background context surrounding Segrè's mistake helps illustrate how such errors can happen. When something like the discovery of a new element has been so desperately sought by so many people for so long, it is perhaps little wonder that a scientist's mind can become fixated on this particular prize in a way that alters their judgment.

A few years before, an American scientist named Ernest Lawrence devised an "atom smasher" that could be used to produce a large number of radioactive elements at once. He called it a cyclotron. On hearing that it was made from molybdenum, Segrè asked Lawrence to send some sample strips from one of the machines; when he did, Segrè found traces of element 43 on them. This was the first man-made element, a fact Segrè and Perrier honored by calling it technetium, from the Ancient Greek word for "artificial." Later in life, Segrè—who became a historian of science—reflected on how he and Perrier had the chance to discover nuclear fission during this time, an opportunity which for some reason they let pass them by.

Segrè's reflections from later in life, after he became a historian of scientist, raise an important point: one reason why scientists might make mistakes is if they do not have enough time and distance to reflect on the research they've been doing. Certain forms of knowledge are only possible to attain after a substantial amount of time and reflection.

In 1940, scientists widely assumed that the elements surrounding uranium on **the periodic table** were transition metals, when in fact they behave more like rare earths. This misstep was due to the fact that these scientists "didn't take periodicity seriously enough" and assumed there were more anomalies in the table than is actually the case—something that is easy to see in hindsight but was difficult at the time. After an attempt to find element 93 with a colleague, Edwin McMillan, Segrè concluded their endeavor to be unsuccessful, which he announced in a published paper. However, McMillian himself soon realized that the problem was that they had assumed the samples they'd been examining behaved like rare earths, but were actually "cousins" of this group of elements.

Kean's argument that scientists "didn't take periodicity seriously enough" might sound over simplistic or even condescending from a contemporary perspective. However, bear in mind that at the time, scientists were still figuring out how strict the rules of periodicity were (meaning how closely the elements followed the laws of the periodic table and how many anomalies from these laws there were). The concern of how seriously to take periodicity was still very much an open question with an evolving answer.

McMillan returned to the experiment with another colleague, leaving Segrè out. He realized that he and Segrè had misidentified the original result in what was, ironically, the exact opposite of another major mistake Segrè had made before. McMillan ended up winning the 1957 Nobel Prize in Chemistry for this work.

For a scientist make two totally oppositional mistakes might seem crazy, but it is possible that the second one was perhaps the result of Segrè overcorrecting for his initial error. Again, this anecdote emphasizes human imperfection, even within highly specialized fields.

Linus Pauling, meanwhile, revolutionized the field of chemistry by showing how quantum mechanics determines the chemical bonds that form between atoms. This led to other major discoveries, such as the fact that sickle-cell anemia is triggered by faulty molecules, a realization that radically transformed the field of medicine. Pauling was essentially concerned with how something like protein shape was determined by the behavior of molecules that made up a protein. This meant that what he was interested in was DNA—however, he did not become aware of this fact until 1952. DNA had actually been discovered by Friedrich Miescher in 1869, but for a long time scientists misunderstood it and misjudged its significance.

This passage provides a fascinating example of how quantum mechanics—which has a reputation of being deeply abstract and distant from everyday applied science—can totally revolutionize fields like biology and medicine. When one changes the understanding of the fundamental building blocks of society, everything else changes too.

Everything changed in 1952, when two geneticists realized that it was DNA, not proteins, that pass on genetic information. At this point, no one knew the shape of DNA strands or how they linked together, information that Pauling was determined to discover. He made some speculative sketches and calculations, then asked a graduate student to check his work. When the student explained the flaw in Pauling's speculation, Pauling ignored him, seemingly too excited by the prospect of being the scientist to solve DNA. He published his model, which his son, Peter, showed to two other students in his lab at the University of Cambridge: James Watson and Francis Crick.

While many of the mistakes discussed in this chapter aren't blameworthy, in this passage Pauling exhibits one of the most fatal flaws a scientist can have: hubris. By ignoring a graduate student who correctly pointed out a flaw in his work, Pauling overestimated his own abilities and forgot that he was capable of making mistakes, something a scientist—no matter how great—must never do.

Watson and Crick were shocked to find that Pauling's idea was a recapitulation of a model they themselves had built the year before but it was discarded when a colleague, Rosalind Franklin, had proven it wrong. Watson and Crick immediately told their adviser, Nobel Prize-winning William Bragg, that Pauling had published a paper that repeated their mistakes. Bragg considered Pauling a rival and was excited by the prospect of one-upping him. Peter Pauling warned Linus that Watson and Crick were at work trying to prove his model wrong, but Linus remained foolishly confident in it. Watson and Crick, meanwhile, made a breakthrough, finally figuring out how the two strands of DNA fit together so perfectly, like "puzzle pieces." They concluded that DNA was shaped like a double helix and in 1953 published this model in *Nature*.

Here Linus Pauling doubles down on his initial hubris when he ignores Peter's warnings that Watson and Crick were proving that he'd make a mistake. Perhaps Linus had trouble imagining that someone in a subordinate position to him (i.e., his son or a graduate student) could see errors that he couldn't. On the other hand, perhaps he had his heart so set on his discovery being true that he couldn't bring himself to admit it wasn't.

Pauling reacted to the whole situation with "dignity," immediately owning up to his mistake and supporting Watson and Crick's work. Things improved for both Segrè and Pauling after 1953. As research began to be conducted on the subject of antimatter, the scientific world acknowledged that Segrè had laid the groundwork for this research to take place; as a result, he was awarded the Nobel Prize. Pauling also got an "overdue" Nobel in 1954. Following this, he began experimenting with taking vitamin supplements, forming the beginning of the entire supplement industry. Meanwhile, sticking to the same principles that led him to refuse to participate in **the Manhattan Project**, he became an activist against nuclear weapons. Pauling won a second Nobel in 1962—this time the Peace Prize—the same year Watson and Crick were awarded the Nobel Prize in Physiology or Medicine.

Fittingly for a book that considers how mistakes are not always disastrous for the scientific community, this chapter on mistakes ends in a happy, positive way. Errors don't necessarily define or ruin a scientist's career, as long as the scientist in question deals with the mistake in a considered, dignified, and honest manner.

CHAPTER 9: OUCH-OUCH

In eighth-century Japan, miners were digging for precious metals such as gold, lead, silver, and copper in the Kamioka mines. It look over a thousand years for people to realize that the mine also contained another, much nastier element: cadmium. While mining for zinc, the miners would heat the zinc and wash with acid in order to remove the excess cadmium, which was then discarded into streams or the soil. Cadmium is too valuable these days to be wasted in this manner—it is used in batteries and computers and it was previously even used as a tanning agent. Moreover, people now understand that cadmium is very poisonous.

This passage introduces a field of knowledge in which contemporary understandings of science are retroactively applied to the past in order to explain mysterious (or misunderstood) phenomena. The fact that it took over a thousand years for people to realize that the toxic element cadmium was also being mined (and dumped) is incredible considering that cadmium is so toxic.

In 1912, rice farmers living near the Kamioka mines were struck by a horrifying, unknown illness, which by the 1930s and 40s had spread all over Japan. It came to be known as "*itai-itai*" or "ouch-ouch." After the end of World War II, a doctor named Noboru Hagino realized that the disease was being caused by rice absorbing cadmium like a "sponge." Hagino published his findings and although the mining company initially denied all responsibility, it was eventually forced to pay 2.3 billion yen every year in restitution to the victims.

Corporate misuse and abuse of the elements does not feature particularly prominently in the book, although it is a major feature of the history of humanity's interaction with the periodic table. In this example, the corporation in question was at least brought to justice and the victims given some level of support.

Unfortunately, this was the fourth time in the 20th century that the Japanese population was struck by poisoning: collectively, these incidents came to be known as "the Big Four Pollution Diseases of Japan." This is not to mention the radiation poisoning that affected many after the U.S. nuclear attacks in 1945. The very worst poisons on the periodic table are thallium, lead, and polonium, which sit on the bottom right corner of the table. Of these, thallium is the most deadly. In the 1960s, a British man named Graham Frederick Young deliberately poisoned his family members with thallium, which he sprinkled in their tea. He was placed in a mental institution, but after getting out poisoned a series of his bosses, deliberately giving them small doses in order to prolong their suffering.

One of the scariest things about the natural world is that matter that is simple and easily accessible to humans can be extraordinarily deadly. This makes sense when one considers how toxicity is simply controlled by a given element's atomic structure, yet this doesn't necessarily make it any less alarming. If a person wants to enormous great destruction to others, the materials do so are often already within their reach.

Young's victims are just some of a long series of people who have murdered by thallium. The CIA once even tried to humiliate Fidel Castro by lining his socks with thallium, which they hoped would make his hair fall out. (This plan was never actually executed.) Bismuth has a more unexpected role among the poisons of the periodic table. It is an extremely beautiful element and one of the few that expands when it freezes. It also has a half-life (the time it takes for half a substance to decay) of an incredible 20 billion years, meaning it will be the last element to stay intact before going extinct.

The story about Fidel Castro adds a much needed light-hearted element to this rather terrifying chapter. It is curious, however, that the CIA did not plan to murder Castro using thallium (something that Young proved was quite easily possible), but only humiliate him. Perhaps they thought that making him lose his hair would actually do more damage than killing him and thereby turning him into a beloved martyr.

Bismuth's position on the periodic table implies that it should be a terrible poison. However, in actuality it is not harmful at all, and in fact is used in medicinal products, such as Pepto-Bismol. Its location on the table is therefore puzzling. It is a "freakish anomaly" that could be thought of as existing in a hybrid category of its own—a "noble metal." Polonium, the element below bismuth, is much more sinister. It was used to poison the former KGB agent Alexander Litvinenko.

Earlier in the book, Kean wrote that "geography is destiny," meaning that an element's placement on the periodic table determines its properties. While this is generally *true, the information provided in this passage serves as a reminder that it isn't* always *true, and that sometimes elements behave in a manner that defies their geography.*

In the 1990s, a well-meaning 16-year-old Eagle Scout named David Hahn built a nuclear reactor in his backyard in an attempt to solve the global energy crisis. David was obsessed with chemistry and had a habit of performing highly ill-advised experiments, often to disastrous results. At school he was not a capable student, yet in his enthusiasm taught himself about the three main nuclear phenomena: fusion, fission, and radioactive decay. He decided to construct a "breeder reactor," wearing a dentist's lead apron and throwing away the clothes he wore while working in order to attempt to protect himself from radioactivity.

David Hahn was vilified in the media, which published sensationalist news pieces about his attempt to build a nuclear reactor in his backyard. These pieces often failed to clarify that such a thing isn't actually possible for someone with the total lack of resources that Hahn had. At the same time, Kean arguably overcorrects the media's bias, making Hahn seem benign and innocent when he engaged in extremely risky and destructive behavior.

Many of the elements Hahn needed for his reactor were readily available. He ended up importing uranium from a "sketchy supplier" in the Czech Republic but—fortunately for the world—he didn't get the volatile kind needed for his experiment to work. Despite what hysterical media reports stated afterward, Hahn did not come close to building a successful reactor. He may have given himself radioactive damage, but beyond that his attempt harmed no one. Later in life, Hahn joined the navy before eventually returning to his hometown. In 2007 he was caught stealing smoke detectors from his apartment building, a worrying offence considering smoke detectors contain the radioactive element americium. The bleeding skin visible in Hahn's mugshot revealed that he'd almost certainly poisoned himself in the process of his experiments.

The reader doesn't need to actually see the image of Hahn's face bleeding in his mugshot to find this detail highly disturbing. Again, while Hahn may not have been an evil person, his reckless determination to pursue nuclear experimentation on his own is certainly odd and rather eerie. Nuclear physics may be fascinating, but it's also incredibly dangerous—most people are put off trying it at home for good reason.

CHAPTER 10: TAKE TWO ELEMENTS, CALL ME IN THE MORNING

Elements often behave in surprising, contradictory ways when they interact with the human body. Humans have been using elements for medicinal purposes for a long time. Silver, for example, has been used to improve health since ancient times. In the 16th century, a "gentleman astronomer" named Tycho Brahe had his nose cut off during a drunken duel. He supposedly commissioned a silver prosthetic nose to wear afterward. When archaeologists found the nose they discovered it was actually copper—yet both elements work well for the purpose of prosthesis, as they have antiseptic qualities.

While much of the Western world's understanding of the elements prior to the modern period was confused (to say the least), people did tend to have some knowledge of how the natural materials around them worked. Evidence of this can be found in stories like Brahe's, who knew to commission a copper or silver nose as this wouldn't get infected.

Copper began being used in a public health context in the 1970s, after a group of hotel guests in Philadelphia became ill due to bacteria in the hotel air conditioning vents. Thirty-four people died from the illness, which was named Legionnaire's disease. In the aftermath, copper was used in air and water systems in order to prevent the spread of bacteria in the future. Vanadium has a similar capacity to kill "small wriggling cells" and can be used as an effective spermicide. However, it has negative side effects, as is often the case when using an element for a particular purpose. Gadolinium, meanwhile, is used in MRI machines due to its ability to illuminate tumors, distinguishing them from healthy tissue.

The reader may still be reeling from all the horrifying uses to which science is put during war. Here, Kean reminds us that the elements also have remarkably progressive capacities that have improved and saved countless human lives.

Furthermore, scientists hope to be able to use gadolinium to treat cancer because of its capacity to inhibit proteins that repair DNA, which could stop tumor cells healing and growing. Unfortunately, gadolinium also has negative side effects, such as causing kidney problems and muscle stiffness. Experimenting with the health benefits of elements is highly common; almost every nontoxic element is being used by someone, somewhere as a supplement. However, this can have unintended consequences. People who ingest copper and silver, for example, might find that their skin turns blue as a result. This happened to Stan Jones, a Montana libertarian who ran as a candidate for the U.S. Senate in 2002.

Much as it is surprising that David Hahn wanted to try and build a nuclear reactor in his backyard, it might seem odd that people are willing to take such big risks by consuming elements when they don't fully know the consequences (such as turning blue, in Stan Jones's case). Perhaps people's reckless attitude with elements emerges from the fact that most elements are "natural," rather than man-made. Of course, as the book has shown by now, such a distinction is actually rather meaningless and certainly not a guarantee of health.

Jones began taking silver due to panic over what he believed was the apocalyptic threat of the supposedly imminent Y2K computer crash, which he worried would make it impossible to access antibiotics. He lost the election, but expressed no regret over taking silver, despite its colorful effect on his body. In any case, "complex," carefully designed compounds tend to make better medicines than pure elements. Despite this, a few elements do play an important role in medicine. Two scientists, Gerhard Domagk and Louis Pasteur, discovered a quality of biomolecules called "handedness," meaning that molecules such as proteins can be either right- or left-handed.

Jones's decision to take silver shows the profound effect of pseudoscience on people's minds. Y2K refers to a widespread fear that the new millennium would cause a computer glitch that would essentially make all computers and related operating systems stop functioning when the clock struck midnight on January 1, 2000. It was significantly overblown by public hysteria.

Pasteur is also significant for developing the process of pasteurization, a way of heating milk that kills disease-causing bacteria. In 1935, Domagk's daughter Hildegard accidentally impaled her hand with a sewing needle, which snapped off inside her. She became ill with a terrible infection thanks to bacteria inside her wound. Domagk had been conducting experiments on a red industrial dye in his lab, which he'd come to realize had the potential to fight lethal bacteria. Yet Domagk was (understandably) hesitant to use the dye to treat Hildegard, when he'd previously only used it on mice in his lab.

Throughout the book, there have been several examples of domestic incidents in the lives of scientists intersecting with their emerging theories and experiments, thereby helping them to understand what might have been previously abstract. In this case, Hildegard's injury not only added context, but a vital sense of urgency to Domagk's research.

Years earlier, Pasteur had gone rogue and treated a young boy with a rabies vaccine that had thus far only been tested on animals. This was a criminal offense, yet it succeeded in saving the boy's life. In desperation—and in violation of "pretty much every research protocol you could draw up"—Domagk decided to steal some of the drug he'd been developing from his lab and inject Hildegard with it. Miraculously, it worked, and Hildegard recovered. This was prontosil, the "first genuine antibacterial drug," which revolutionized the world to an unimaginable degree. Yet Domagk was a bacteriologist with limited understanding of the chemistry behind his successful experiment.

In both these stories choosing to break the laws of science paid off, making Pasteur and Domagk appear to resemble rebellious heroes who save the day by ignoring prohibitive rules. In reality, of course, the rules of scientific and medical ethics serve a very important purpose and it is not usually a good idea to break them. In fact, Pasteur and Domagk's actions are arguably only excusable if it was certain the victims they treated were going to die anyway (which does seem to be the case).

Prontosil didn't gain popularity as a drug until it was used to save the life of Franklin Delano Roosevelt Jr. from a bad case of strep throat in 1936. At this point, scientists from the Pasteur Institute in France located the paper Domagk originally published on prontosil and, looking at his findings, concluded that it was not prontosil itself that killed bacteria, but rather a compound called sulfonamide which was produced when mammal cells split prontosil in half. Prontosil stopped bacteria from spreading. It wasn't a "bacteria killer"—it was "bacteria birth control." For this discovery, Domagk was awarded the 1939 Nobel Prize in Medicine or Physiology. This, in turn, provoked the ire of Hitler, who hated the Nobel committee due to their having awarded an anti-Nazi journalist the Peace Prize in 1935.

The difference between being a "bacteria killer" and a "bacteria birth control" might not seem significant, especially considering both perform essentially the same function of stopping disease. However, for scientists a distinction like this means everything—so much so that Domagk was awarded the Nobel Prize for it.

Alongside Domagk's personal difficulties, he also had to face the reality that sulfonamide became a "dangerous fad" that people took too often and bought on the black market, where it was mixed with lethal antifreeze. Meanwhile, Pasteur's research led to the development of antibiotics. For a long time, Pasteur's claim that "handedness" was what separated dead cells and living cells was taken as gospel within the scientific community. Yet experiments that followed this principle often went terribly wrong, such as when a German company sold thalidomide as a cure for morning-sickness, not realizing that the "wrong-handed" form of this chemical caused drastic birth deformities.

While contemporary readers might assume that scientific or medicinal fads are a product of the internet age, when misinformation spreads across the world with rapid ease, this passage is a reminder that this problem has existed for a very long time. People are always eager for comforts and cure, which means that they sometimes won't perform necessary scrutiny over the cure they are so desperate to embrace.

Yet while this was taking place, an American chemist named William Knowles was experimenting with an element called rhodium and coming to realize that inanimate (dead) chemicals can be "tricked" into only making one hand. This was the origin of modern drug synthesis. In Knowles' case, the drug rhodium produced was levo-dihydroxyphenylalanine, known as "L-dopa." Similar to the neurotransmitter dopamine, it had revolutionary potential for treating Parkinson's disease.

Knowles's discovery shows how a somewhat abstract scientific principle—such as "handedness"—can be used to extraordinary practical effect as long as there are scientists smart and inventive enough to discover the right way to use it.

CHAPTER 11: HOW ELEMENTS DECEIVE

Elements might behave in a predictable way in an atomic sense, but when they come into contact with "the chaos of biology," the results can be bewildering. In 1981, five technicians were working on a simulation spacecraft at the NASA headquarters at Cape Canaveral in Florida. The technicians undid a panel, then—immediately—peacefully passed out. Back in 1967, NASA had a policy of only having pure oxygen inside spacecrafts, rather than normal air (which contains 80 percent nitrogen). Yet, as the agency was about to tragically be reminded, oxygen makes fire rage far faster than normal air, and a fire can be provoked in pure oxygen by almost nothing—something as little as the static from Velcro.

Of all people, one might imagine that those working at NASA would understand something as seemingly simple as the relative danger of different concentrations of gas inside a spacecraft. However, the book has proven over and over that aspects of the world that seem most simple are often most confusing for scientists. A solution might look easy or obvious, but that does not mean it actually is.

In 1967, this led to three astronauts being burned to death when a spark went off inside a grounded spacecraft filled with pure oxygen. As a result, by 1981 NASA had a policy of filling spacecraft compartments with nitrogen in order to prevent such fires. Unfortunately, on this fateful day, someone accidentally signaled for nitrogen to be pumped into the spacecraft while the technicians were still inside. Two of the five technicians who lost consciousness inside the spacecraft died from lack of oxygen. Death by nitrogen exposure is frightening because no one realizes if it happens to them. Rather than a feeling of suffocation, nitrogen will cause a person to peacefully pass out. Even scarier, nitrogen is invisible and odorless.

This horrifying story shows how powerfully the balance of elements around humans can affect the body. The air is already mostly nitrogen, so it is not as if this element is entirely toxic to the human body. However, too much nitrogen will make a person lose consciousness without even realizing it.

In 1952 a Swedish doctor named Per-Ingvar Brånemark was conducting a gruesome experiment of boring holes in rabbits in order to observe how bone marrow generates blood cells. He attached little titanium "windows" the holes in the rabbit fur, yet when he tried to remove these, they remained stuck. Incredibly, this was the beginning of modern prosthesis. For centuries, humans could not figure out how to properly "integrate" prosthetics into the human body. Bone-forming cells cannot distinguish between titanium and real bone, allowing titanium to "fully integrate itself into the body." Ever since Brånemark's discovery it has been used for implanted teeth, sockets, hips, and fingers.

The story of Brånemark's window getting stuck inside the rabbit he was dissecting is extraordinary. Once again, it illuminates how accidents and coincidences are so often the driving force of scientific innovation. Even the most intelligent scientists' imaginations are starkly limited compared to all the gloriously weird, unpredictable, and unexpected quirks of the universe.

The human sensory system is even more complex than the immune system, and tricking the sense can be highly difficult. Elements can have bizarre effects on our sensory system. Coming into contact with tellurium will make a person stink of garlic, whereas if a person licks beryllium, they will find it tastes like sugar. Unfortunately, beryllium is also highly toxic. Taste buds are usually alert to poisonous foods, which is why cyanide, for example, tastes horribly bitter. However, beryllium overrides this system. Moreover, sensual experiences—such as eating something sour—really only provide an approximation of what is actually going on. For example, our mouths can easily mix up the taste of an electrical charge with sourness.

The human body's confused reaction to elements shows how ill-equipped we are to recognize substances in the wild outside of the small group of elements and compounds that ordinarily surround us.

Saltiness is also the result of electrical charge, but humans can similarly be tricked into experiencing saltiness by something that isn't charged like sodium. All in all, humans are sensually ill-equipped to distinguish between elements. Kean argues that "if you inject a random element into our bloodstream or liver or pancreas, there's almost no telling what will happen." Iodine, which has proven to be a deceptive element more than once in the history of science, played an important role in the life of Mahatma Gandhi, who apparently despised the element. In 1930, Gandhi led what was called the Salt March in protest against the salt tax of the British colonial government.

Kean's statement about injecting a random element into a person's bloodstream is perhaps a little confusing, as it is not totally clear what he means by "random." The effects of certain elements on the human body have been extensively tested, so by "random" Kean likely means the ones that haven't been tested. In any case, the sentence is meant to emphasize that much is still totally unknown about the ways elements and the human body interact.

The salt tax was brutally greedy and oppressive. Gandhi encouraged people to produce untaxed salt, thereby breaking colonial law and (hopefully) weakening the power of the British imperial government. However, a problem arose via the fact that Western countries had started adding iodine to salt. Although there were known health benefits to doing so, Indian people were reluctant to take up the practice due to its association with Western colonizers. Huge amounts of common (non-iodized) salt were produced in India, which led to a sharp rise in birth defects. Unfortunately, the ramifications of this lack of iodine continue into the present day. The philosopher Bertrand Russell used the profound effect of iodine on the human brain as evidence that humans are purely physical beings, controlled by chemistry rather than souls.

One critique of Kean's book might be that he tends to focus solely on Western science, when in reality there are a great diversity of indigenous scientific practices all over the world. Furthermore, Western science is increasingly acknowledging that indigenous scientific traditions often understand their local landscape better than Westerners. This is the case, for example, with the farming techniques of Aboriginal Australians, which prevent wildfires far better than Western farming practices.

CHAPTER 12: POLITICAL ELEMENTS

Humans are flawed beings and thus **the periodic table**, which is a human invention, is necessarily flawed as well. As the reader has witnessed thus far, the periodic table may strive to be scientifically pure and objective but in reality is endowed with all the social problems, influences, and biases that surround its creation. When Marie Skłodowska—one of the most important Poles to ever live—was born in Warsaw in 1867, the Polish city was technically part of tsarist Russia. Educational opportunities for women were limited; after being tutored by her father, Skłodowska moved to Paris to study for her PhD at the Sorbonne. It was here that she fell in love with her future husband, Pierre Curie.

Again, this passage emphasizes that Marie Curie—one of the most important scientists to ever live, whose work profoundly changed the world—might have easily never become a scientist at all, simply by being denied an education. The reader is led to imagine all the women like Marie Curie whose fathers wouldn't (or couldn't) tutor them, or who were too poor to study, or who would have been denied access to the Sorbonne due to racism, and so on.

Marie and Pierre Curie had "perhaps the most fruitful collaboration in science history" thus far when they worked together in the 1890s. Studying uranium, Marie concluded that the radioactivity of an atom was unaffected by whatever electron bonds it may have. This vastly simplified—and enhanced—knowledge of radioactivity. She and Pierre were jointly awarded the 1903 Nobel Prize in Physics as a result. Like many 20th-century scientists, Marie was a refugee whose career was obstructed by imperial politics. Shortly after her Nobel Prize win, Marie noticed that the waste produced during the process of purifying uranium was 300 times more radioactive than the uranium itself. She immediately set to work researching what could explain this and ended up discovering two whole new elements. She won a second Nobel (in Chemistry this time) in 1911.

As this passage shows, one of the main aims of science is to simplify existing knowledge. If scientific principles are too complicated—or if a rule has too many exceptions—then this is often a sign that scientists have misinterpreted the rule or are missing vital knowledge. This isn't because the universe is necessarily simple but because there is a certain elegance to natural laws and principles. Messiness is usually an indication that human knowledge has gone wrong somewhere.

Marie named one of the elements polonium, after her "nonexistent" home country. It was the first time an element had been named for political reasons in this manner. Pierre was tragically killed in a street carriage accident in 1906. Shortly after, Marie was rejected from the French Academy of Sciences due to her gender and the suspicion that she was Jewish (she wasn't). Not long after that, a newspaper published correspondence between Marie and her colleague, with whom she was having an affair. Fortunately for her (though not the world), World War I soon distracted the public from anything as trivial as her personal life. Polonium did not go down in history as a very important element. Ultimately, both Marie and her daughter, Irène, died of leukemia provoked by radiation exposure from their scientific research.

As Marie and Irène's fates show, even the most intelligent scientists sometimes fail to predict the consequences of their research—including on themselves. Marie was working at the very early stages of knowledge about radioactivity and it is thus not so surprising that she did not realize how handling radioactive atoms would affect her. Of course, it is poignant and tragic that her similarly gifted daughter met the same end.

In 1910, a Hungarian aristocrat named György Hevesy began studying radioactivity in Manchester, England, under Ernest Rutherford. Frustrated with his inability to separate radium-D, Hevesy changed tactics and decided to inject a small amount into a living creature to see if the radioactive and nonradioactive lead that together constitute radium-D. He first tested it on dead tissue—in fact using the unappetizing meat that his landlady served him for dinner. He succeeded in detecting radiation in the meat, a discovery that triggered an upward turning point in his career. In 1920, he moved to Copenhagen to study with the quantum physicist Niels Bohr. This was at a time when the disciplines of chemistry and physics were moving further and further apart.

Kean's note about the fields of chemistry and physics moving apart might seem rather uninteresting, of relevance perhaps only to historians of science. However, this could not be less true. The splitting of science into multiple distinct disciplines—and the solidification of those discipline as distinct—has had a profound effect on research and knowledge. While there are many advantages to having specialists in each particular subdiscipline, it has also prevented visionary, cross-disciplinary work from taking place.

At the time, element 72 was yet to be discovered. According to legend, Bohr developed a mathematical proof that 72 was not a rare earth based on quantum mechanics. Working alongside a physicist and based on Bohr's calculation, Hevenesy found 72 on his first try. The team named it hafnium, after the Latin name for Copenhagen. Despite this success, chemists tended to remain suspicious of quantum mechanics. Bohr won the 1922 Nobel Prize in Physics; around this time, people began to spread rumors that he had prophetic abilities. However, these beliefs were strongly influenced by legends that didn't quite match up to reality. The calculation that Bohr made, which led to the immediate discovery of element 72, was actually built off the research of three chemists who'd come before him.

Modern science may seem miles away from the old practice of alchemy, wherein people used magical explanations for material phenomena. However, the awed speculation that Niels Bohr had prophetic power shows that these two historical moments—and forms of knowledge—are actually not as different as one might assume.

The legend surrounding Bohr was mostly a testament to people's enthusiasm about quantum mechanics. Hevesy was nominated for the 1924 Nobel Prize but—in part due to the way he straddled both physics and chemistry—he did not win. He moved to Germany and he was repeatedly nominated for the Nobel without winning, eventually returning to Copenhagen in the 1930s due to his Jewish ancestry. However, Nazi soldiers then arrived in Copenhagen in 1940 and destroyed Hevesy's office searching for Nobel Prize medals he was keeping for two German winners, one of whom was Jewish and both of whom were persecuted by the Nazis. However, the soldiers didn't find them, as Hevesy had already dissolved them in hydrochloric acids. Hevesy managed to successfully flee Copenhagen, returning after the end of the war.

The book has jumped back and forth through history several times, but has now arrived back at World War II. During this period, exciting developments in science were thwarted by fascism and conflict. Additionally, major Jewish scientists had their work—along with everything else—stolen from them by the Nazi regime.

Lise Meitner was a German scientist who worked with a collaborator named Otto Hahn. Together, they proposed renaming the recently-discovered element brevium to protactinium. The Polish chemist who discovered the element, Kazimierz Fajans, narrowly lost out on the 1924 Nobel Prize for Chemistry for reasons that were never fully clarified. In any case, Meitner and Hahn were successfully in lobbying for the name to be changed to protactinium, and sometimes they are given credit for discovering the element itself. Meitner and Hahn had an extremely close (though platonic) bond. Despite the sexism of the time, Hahn recognized Meitner's extraordinary talent.

Of all the notable and important women scientists Kean mentions, almost all worked in partnerships with men. This was not because they needed men's input or were less capable, but rather because they would simply not be granted access to scientific institutions or funds and not be taken seriously unless an esteemed man was working alongside them.

The two made a good team, with Hahn focusing on the chemistry side of their work and Meitner on the physics. However, for the protactinium experiments Meinter ended up doing all the work, as Hahn was focused on the development of gas warfare. Yet Meitner still shared the credit with him equally. After the war, when the Nazis began a crackdown on Jewish scientists, Hahn—a gentile—resigned from his professorship in protest. Meitner's parents, however, were Jewish converts to Protestantism. Yet she attempted to ignore the escalating threat posed by the Nazi regime, instead focusing on her work.

Meitner and Hahn weren't just scientists of different genders—they were also in separate categories according to the Nazis' racist system of categorization. Meitner may have been a convert to Christianity, but the Nazi regime cared about ethnicity, not religion. Hahn's decision to resign in protest at least seemed to indicate that he was willing to make sacrifices to stand in solidarity with Meitner and other Jewish people.

Meanwhile, scientists around the world were fixated on the question of whether, as Irène Joliot-Curie argued, the newly discovered transuranic elements could behave like lanthanum, which was a rare earth on the other side of the periodic table. In 1938, a colleague attempted to turn Meitner in to the authorities, and she fled to Sweden. She and Hahn continued their collaboration via letters and would meet secretly in Copenhagen. During one meeting, Hahn explained that he'd repeated Joliot-Curie's experiments and found that the new elements weren't like lanthanum—they appeared to be lanthanum (and barium). Whereas Hahn was bewildered, Meitner realized that Fermi hadn't discovered new elements as everyone believed—he had discovered nuclear fission.

The fact that one of Lise Meitner's colleagues tried to turn her into the authorities challenges misconceptions about fascism that are particularly prevalent in the present day. Some people claim that the poor and uneducated are more likely to support far-right and white supremacist policies and that the highly-educated elite—including scientists—tend to be more tolerant. Unfortunately, as Meitner's story shows, scientists are just as capable of embracing fascism as anyone else.

Hahn and Meitner knew that publishing this finding under Meitner's name would be politically dangerous and Meitner thus agreed to have it be published in Hahn's name only. After the war ended, the Nobel committee knew they wanted to award the Physics prize to work on nuclear fission. They were unsure whether Meitner or Hahn deserved it; there was certainly an extent to which they knew the pair had conducted research together, however one member argued that Hahn clearly deserved all the credit as Meitner hadn't done anything significant in the past few years. (Of course, this was because she was a refugee hiding from the Nazis.) When Hahn was awarded the Prize, he didn't mention the truth about his debt to Meitner. Meitner never won a Nobel, but in 1997 the element "hahnium" was renamed dubnium, while another new element was christened meitnerium.

The terrible twist in this story is a sad reminder of the way in which people can betray trust, particularly in a climate of fascism and particularly when there is something like the Nobel Prize at stake. Hahn clearly cared about Meitner (along with other people of Jewish descent) to some degree, but perhaps the effects of the Nazi regime normalized prejudice to him and made him lose touch with his principles. Or perhaps he was simply focused on his own personal gain, knowing that Meitner—who was in such a vulnerable social position—would have no one to stand up for her, allowing him to take advantage and steal credit for work she'd done.

CHAPTER 13: ELEMENTS AS MONEY

Ever since metals started being used to make currency, the issue of counterfeiting has been a major concern. In the Ancient Greek myth about Midas, the king asked a satyr to give him the power to turn everything he touched into gold. This blessing turned out to be a curse, in part because when Midas's beloved daughter turned into a gold statue after he embraced her. Meanwhile, the real King Midas ruled over the part of Asia Minor containing the earliest foundries of brass, an alloy (mix) of copper and zinc. This provides a clue to where the real King Midas meets the Midas of myth. People may have seen the real Midas adorned with what they believed to be gold, when it was actually brass.

One of the most fascinating powers of science is its ability to explain (or provide educated speculations about) the origins of ancient myths. The story of King Midas and his golden touch might appear to be nothing more than baseless fantasy, but as this passage shows, it could have actually been inspired by chemistry.

The myth of El Dorado is another example of human culture's fascination with gold. This myth foreshadowed the real-life gold rushes, wherein many were tricked by elements that resemble gold, but are actually worthless. One lucky man who did strike real gold was an Irishman named Paddy Hannan, who was riding through the Australian outback when he happened upon a spot in the desert where "gold was more plentiful than water." Miners quickly rushed to the scene, where much of the rocks they found were tossed to one side, assumed to be worthless. However, chaos broke out when the miners realized the rocks they'd thought were useless was actually calaverite, a gold telluride. The spot soon became the biggest source of gold in the world and was named "The Golden Mile."

The transition from the myths of King Midas and El Dorado to the true story of the gold rush in Australia reminds the reader that real life can be mythic, too, and that the most fantastical sides of existence are often found in the wonders of the natural universe.

Nowadays producing counterfeit money is categorized as fraud, but in the past it was considered to be the highest possible type of crime: treason. Despite the enormous consequences of counterfeiting, people have still done it throughout history. While Isaac Newton was master of the Royal Mint of England, he enthusiastically devoted himself to going after counterfeiters (known then as "coiners"). A Mongol emperor was the first to start using paper money in the 1200s but this form of currency didn't arrive in England until 1694. At the time, coins were easier to counterfeit than paper money (although now the reverse is true).

The fact that coins used to be easier to counterfeit than paper money shows how much humanity's relation to matter can change within just a few centuries. The materials that surround us (and the elements that make them up) are constantly shifting, and in turn, humanity is continually adjusting to these shifts.

The path of orbit that an electron makes around an atomic nucleus is determined by which shell it is in. However, electrons can jump between shells, and when they do so they emit light, which in turn emerge in "bands of color." (These are what Bunsen analyzed with the spectroscope.) Lanthanides emit light in a fluorescent manner, meaning they absorb high-energy light but emit it as low-energy. In the European Union, fluorescent dye is used as an effective anti-counterfeiting tool because it will look normal in ordinary light but a special laser will reveal whether it is fake. As this story shows, elements are just as important to making real currency as they have been to the history of counterfeiting.

Cash is a great example of how advanced scientific technology is infused to the most ordinary, everyday objects, often without people realizing it. Most people probably exchange cash every day without even really noticing what's in their hands, let alone realizing that it contains highly advanced scientific technology based on the principles of the periodic table.

During World War II, the Italian Jewish writer and chemist Primo Levi traded cerium with local workers while in a concentration camp in exchange for life-saving food. After surviving, he published a book named *The Periodic Table*. Metals are one of the most stable sources of value in human history. The person who made the most money from **the periodic table** was Charles Hall, an American chemist who was the first person to devise a way to separate aluminum from oxygen, which is how it is found throughout the earth's crust. Many had tried and failed to do this before, but what made it all the more impressive is that Hall was only 23 at the time of his discovery.

The Periodic Table *is a kind of scientific memoir written in the form of a collection of stories. Each of these stories is named after a different element (although the whole table is not covered) and how this relates to an incident in Levi's experience of the Holocaust. Although this a similar principle to the one organizing* The Disappearing Spoon, *the books are extremely different. Still, for a much more sobering perspective on the elements' interaction with human history, Levi is a great place to start.*

The company Hall founded began selling aluminum at a cheaper and cheaper price, while Hall himself made a fortune. By the time of his death, his shares in his company were worth the equivalent of over half a billion dollars. Here Kean notes that he has been using the international spelling "aluminium" rather than the American "aluminum" throughout the book. This is the version used by the scientists who searched for the (at the time undiscovered) element in the 19th century and it is also the spelling initially used by Hall himself. However, when it came to advertising his products, Hall dropped the extra "i," a move that might or might not have been deliberate.

Americans who have had spoken conversations with non-American English speakers (and vice versa) have probably noticed the difference in pronunciation over the word "aluminum." Yet few probably realize that there is a spelling difference, too, and that this difference has a long scientific history that involves the man responsible for mass-producing aluminum foil.

CHAPTER 14: ARTISTIC ELEMENTS

Science has grown expensive over time and this often limits the circumstances under which it can happen and who gets to take part. The fact that many scientists were aristocrats is subtly evident in the periodic table. For example, the Ancient Greek and Latin names of elements can be traced back to the fact that classics was the foundation of humanistic education for the European elite. Even more strangely by today's standards, for many years science was actually considered more of a hobby than a profession. Johann Wolfgang von Goethe—whom many consider to be the be the greatest German writer in history—also dabbled in science despite not being qualified to do so. He even challenged Isaac Newton's theory about how colors work.

This passage is so important that there is a sense in which it is strange to introduce it at such a late point in the book. The fact that most Western scientists throughout history have been aristocratic white men—many of whom dabbled in science rather than properly training in it—is not an incidental feature of the history of science. Instead it is absolutely integral, and if this system of elitism hadn't been present, science would likely look a lot different today.

Goethe's "masterwork" is his telling of the story of Faust, which is filled with unfounded "speculation" about alchemy and geology. Despite his lack of knowledge or credentials, Goethe was involved in selecting a scientist for a professorship in chemistry at the University of Jena in 1809. He picked a man named Johann Wolfgang Döbereiner who hadn't even studied chemistry, although that didn't stop Döbereiner spending many hours chatting with Goethe about how they believed various chemical processes worked. Years later, Döbereiner was measuring the weight of a newly-discovered element called strontium and he was intrigued to find that it lay in the middle of two other elements, calcium and barium.

It is hard to know what to of Döbereiner, an unqualified man nominated by another unqualified man to a chemistry professorship who then went on to make major contributions to the field. Döbereiner's story perhaps suggests that those who don't believe they can achieve much in the sciences should give themselves another chance, since one never knows what might happen.

Döbereiner then began to notice more trios of elements like this and proceeded to group them together. Incredibly, this was the beginning of the columns of **the periodic table**. Not only that, he also invented the world's first portable lighter, which was called Döbereiner's lamp and which brought him global fame. In the 1920s, the artists and design theorist László Moholy-Nagy coined the terms "forced obsolescence," which refers to the natural progress from older to newer technologies, and "artificial obsolescence." This latter term describes when consumers abandon old products for new ones that aren't substantially different, but have a fancy, enticing veneer.

"Planned obsolescence" is a term very commonly used in the contemporary period, perhaps most famously to describe Apple's decision to release new and improved iPhones so regularly at increasingly steep prices. Some might be surprised to learn that the phrase originates with "artificial obsolescence," an idea coined all the way back in the 1920s by one of the major figures of the Bauhaus.

Kenneth Parker was 28 when he persuaded his family business to make a luxury pen, the Duofold pen. A decade later, in the midst of the Depression, Parker debuted a new luxury pen, the Vacumatic. Hoping to use Moholy-Nagy's insight to get rich, he introduced a third pen in 1941, calling it the Parker 51. Although this pen was not substantially different from any other pen (they all perform the same essential function), it became a status symbol and a hot commodity, nicknamed "the world's most wanted pen." Incredibly, at its highest price it sold for $50, the equivalent of $400 today. The Parker 51 eventually fell out fashion due to the rise of typewriters.

One of the criticisms reviewers made of The Disappearing Spoon *is that it makes quite a lot of strange detours and jumps between seemingly unrelated stories. This is arguably an example of such a moment. Of course, it's true that the Parker 51 involved elements and is thus intimately related to the periodic table—yet so is every other material substance on Earth. Regardless, Kean's use of these seemingly unrelated stories underscores the wide variety of contexts in which science and technology can impact people's lives.*

Mark Twain bought a typewriter as soon as he saw one despite the fact that it cost $2,400 in today's dollars. He became the first author to submit a typewritten manuscript to a publishing house. He was also captivated by science and once wrote a story, "Sold to Satan," about **the periodic table**. The story is set against the backdrop of a speculative economic crash and features a narrator who sells his soul to the devil, whose body is composed of head-to-toe radium. Moreover, Satan wears a coat made from polonium (which, at the time Twain was writing, had only just been discovered by Marie Curie). The story features a twist of Satan burning from "within," a nod to the process of radioactivity that fascinated Twain.

Again, via the slightly bewildering connection from Moholy-Nagy to the Parker 51 to typewriters, the reader arrives back at a more explicit invocation of the periodic table. The main character in Twain's story "Sold to Satan" is clearly a kind of Faust figure. Moreover, Satan himself is made of radium, a highly radioactive metal. This is fitting, as radioactivity—while useful—is arguably one of the most terrifyingly destructive forces to humanity.

Perhaps the most Faustian of all the "tales of artists and elements" is the poet Robert Lowell's relationship to lithium. Throughout his life, Lowell experienced hallucinations, delusions, and periods of psychosis. He was also the most celebrated poet in the U.S. Although some romanticized his mental instability as part of his creative genius, in reality he had bipolar disorder, which was caused by a chemical imbalance in his brain. By the time lithium was introduced as a treatment for bipolar, Lowell had just been place in a psychiatric ward. Lithium can't halt a manic episode when it's already happening, but it can prevent one from occurring if taken beforehand. It readjusts the circadian rhythm (body clock) of people whose rhythm has otherwise been thrown off by bipolar disorder.

Kean appears to make the argument here that Lowell's mental instability vitally fueled his creative practice, an idea that some people who experience mental health issues have advocated against. Romanticizing something like bipolar disorder as having a special relationship to genius is tricky territory, particularly considering that doing so can idealize suffering.

Lowell's life drastically stabilized after he started taking lithium. Writing to his publisher, he expressed his astonishment over the fact that all the agony and chaos of his life was caused by "the lack of a little salt in my brain." Yet while lithium brought Lowell stability, it also tranquilized him to the point that his former vitality was all but completely gone.

Again, the notion that Lowell's stability might not have been worth it due to him supposedly losing his poetic vision is something that many mental health advocates would characterize as a dangerous message.

CHAPTER 15: AN ELEMENT OF MADNESS

The archetype of the "mad scientist" shows how closely scientific brilliance can border on insanity. William Crookes was an English chemist who earned a place in the elite Royal Society at only 31. However, not long after, Crookes's brother died at sea, and Crookes was consumed by grief. This was a moment in which spiritualism had taken hold of England. Crookes fell under its spell and started attending séances in order to communicate with his brother. This horrified the scientists at the Royal Society—even more so when Crookes published a scientific paper attempting to justify the spirit world as plausible and real. Before all this happened, Crookes had devoted himself to selenium, a mineral the human body needs in small amounts but which can be toxic in large ones.

There are, of course, many scientists who are also religious believers. Believing in life after death, a spiritual world, and the possibility of communicating with ancestors does not automatically make one a bad scientist. On the other hand, the fact that Crookes attempted to use scientific methods to argue that what was essentially a baseless fad was scientifically plausible did *make him a bad scientist.*

Selenium causes insanity in animals, and thus some might be tempted to believe that this is what happened to Crookes. However, this is unlikely. Crookes eventually turned away from spiritualism, yet pushed forward with his scientific research. He was awarded a knighthood in 1897 and three years later he discovered the element protactinium (although he didn't actually realize this at the time). Crookes had fallen victim to "pathological science," a term that describes highly detailed and internally coherent belief system that uses actual scientific ideas and methods to try and prove that it is true. Believers in pathological science "use the ambiguity about evidence *as* evidence."

Pathological science is both sinister and fascinating. It shows how people can use scientific tools, methods, and terminology to give themselves an air of authority—something that continues to be an enormous problem in the present day. Indeed, if anything, the internet has likely caused a large uptick in incidents of pathological science, along with conspiracy theories and other false forms of belief.

In 1873, a research ship called the HMS *Challenger* scooped up samples from the ocean floor to study. They found what look like "fat, solid, mineralized ice cream cones" that had giant shark teeth inside. Looking at these surprising skeletons, paleontologists guessed that this was a type of enormous shark that could grow to 50 feet long. They called it the "megalodon." Such speculation is normal in the realm of paleontology. Things took at pathological turn when researchers began studying the shark teeth, which they had dated to about 1.5 million years ago, giving a rough estimate of the point when the megalodon died out. However, the researchers then noticed that the manganese plaque on the teeth was only about 11,000 years old.

The story of the megalodon indicates that seemingly legitimate research methods—such as using manganese plaque buildup to date a skeleton—might actually be completely illegitimate. Understandably, it can be difficult for a non-expert to tell the difference. This is why people should first look at dissenting opinions before embracing an argument or system of belief.

Suddenly, people began to speculate that the megalodon may have never gone extinct after all. Although there is no evidence to support this, it is a persistent myth. This is partly because, with a certain mindset, a lack of evidence can be treated as proof of one's existing belief. Far more intense than the pathological science surrounding the megalodon was that fixated on cold fusion. B. Stanley Pons and Martin Fleischmann were once believed to be one of the great pairs of scientists in history; however, now they are remembered only as "imposters, swindlers, and cheats." The two scientists ran an experiment that produced very erratic results, but one of these results encouraged them to "convince them[selves]" that they had discovered cold fusion.

This passage indicates that the stories of William Crookes's spiritualism and the supposedly non-extinct megalodon have a direct tie to the periodic table via the disgraced figures of Pons and Fleischmann. This is not the first time that the book has depicted scientists who were so desperate to believe that they had discovered something that they ignored evidence to the contrary. However, Pons and Fleischmann appear to be the most egregious example of this phenomenon.

Abandoning all patience and precaution, Pons and Fleischmann immediately announced their supposed discovery to the world. They became "instant celebrities" and won the Nobel Prize within a record one year. Scientists were not just excited about the cold fusion revelation but also the fact that Pons and Fleischmann's experiment seemed to have proven that superconductors (matter that can conduct charge with no resistance) could work at temperatures above 400°F—something many thought was simply impossible. Some scientists remained skeptical, pointing out that Pons and Fleischmann had skipped the peer-review process. Indeed, a group of scientists from around the world ended up teaming up to collate arguments that Pons and Fleischmann had faked their results. A fierce argument ensued, with many rallying to defend Pons and Fleischmann. Tired of fighting, the dissenters gave up.

This passage suggests that it was not just Pons and Fleischmann themselves who fell victim to the desperation to believe that cold fusion had been discovered. The fact that the scientific community allowed the pair to skip the step of peer review is evidence that others, too, were overenthusiastic about the supposed discovery. While jealousy is often characterized as a useless emotion, the envy and resentment other scientists felt over Pons and Fleischmann's "achievement" was, in this instance, key to the truth eventually coming out.

Looking back, it is obvious that Pons and Fleischmann knew their trick would be discovered. They must have decided that it was worth the humiliation that followed to feel the exhilaration of scientific glory, even if it was temporary and fake. There are, however, a rare few cases when pathological science has turned out to be right. This includes Wilhelm Röntgen's discovery of invisible rays. In Germany in 1895, Röntgen was repeating an experiment performed by his colleague when he noticed an unexpected beam while shining light through a barium-coated screen. To Röntgen's astonishment, he realized that combining the light with the barium screen mean he could "somehow *see through things*."

The fact that Pons and Fleischmann knew they were going to eventually be found out is important. At least in today's world, scientific fraud isn't like other kinds of deception. Even if there is no doubt that a certain finding is legitimate, it will still be repeated and subject to scrutiny simply because this is how research works. There was never a chance that Pons and Fleischmann's bad findings would just be put to one side and forgotten.

Röntgen briefly thought he was hallucinating. He spent seven weeks in his lab trying to figure out what happened, which he refused to believe could have been "revolutionary." Eventually, he brought his wife into the lab and, self-effacingly claiming that everyone would think he'd gone mad, took the world's first X-ray photograph, of her hand wearing a ring. Bertha was terrified, but the incident confirmed that Röntgen was not mad. Eventually, his terror of anything resembling pathological science relented, and he was able to realize the true nature of his discovery. In 1901, he won the first ever Nobel Prize in Physics.

Kean strongly indicates that scientists should be more like Röntgen and less like Pons and Fleischmann. Skepticism is important, even if this means that one is quicker to doubt one's own sanity that trust that an extraordinary scientific breakthrough has taken place. There is something very moving about Röntgen's humble astonishment and disbelief that he discovered the X-Ray—a revelation that, once again, was the result of an accident.

CHAPTER 16: CHEMISTRY WAY, WAY BELOW ZERO

There is still much more left to discover about the periodic table, but this increasingly involves conducting research at extreme temperatures. In 1911, Robert Falcon Scott and his group of "pale Englishmen" journeyed on what they hoped would be the first human expedition to reach the South Pole. However, when a dwindled group of five of them did manage to reach the pole, they were upset to find a Norwegian flag already there, along with a letter explaining that the Norwegians had beaten them to it by a month. The journey back was horrendous: the weather was especially bad and the men's kerosene supply leaked onto their food, meaning they couldn't cook the little food they had left or melt ice into drinking water.

This passage highlights another way in which people go to extreme lengths in their devotion to the pursuit of knowledge. (Scott's form of exploration is not "science" in its strictest sense, though one could certainly argue for it being a vital part of scientific inquiry.) Throughout history, the thirst for new knowledge about the universe has inspired people to put themselves at great risk and endure terrible suffering.

One of the team died from illness, while another went insane and walked off, never to be seen again. The remaining three are thought to have died of exposure in late March of 1912. Although no one knows the exact fate of the last three men, it is believed that the tin kerosene canisters they were carrying may have undergone an alpha-beta shift due to the cold, a process that can give a white rust-like appearance but is different from chemical rust. When tin experiences an alpha-beta shift, it weakens or disintegrates and can even make a kind of screaming sound. It's possible that this is the reason why the kerosene leaked, dooming the mission. Scott and his men were thus arguably "victims at least in part of **the periodic table**."

Some people—no doubt including many scientists—might object to Kean's argument that Scott and his companions were "victims […] of the periodic table." In a way, this anthropomorphizes the periodic table, suggesting that it actively victimizes people. It might also be argued that everything is the "victim" of the periodic table because the whole universe is governed by its laws. At the same time, Kean's goal with The Disappearing Spoon *is to make scientific storytelling engaging, which is why he uses personification in this way.*

Elements do strange things when they get very cold and shift between the three states of matter (solid, liquid, and gas). In a solid state, atoms line up in crystal formations that can change shape. At very low temperatures, when elements that would usually be in gas form become solid, very strange behavior can result. Noble gases, for example, which usually would resist forming compounds, will react with other elements if they are cold enough. Yet there are still two—helium and neon—which scientists believe have never formed a compound, no matter how ultra-freezing their surroundings.

Every time it seems as if the periodic table is working according to a reasonably straightforward, predictable set of principles, something—such as the vast difference in the elements' behavior triggered by low ultra-low temperatures—comes along to confuse everything again. On the other hand, one could argue that this is what makes science so endlessly fascinating and exciting.

For a long time, scientists believed that superconductors worked at low temperatures because the electrons—which flow across atoms without resistance in a superconductor—had more room to move. Yet in 1957, scientists realized that the qualities of electrons themselves change at these low temperatures. They connect closely to one another, helping them move extremely fast with no resistance. When elements are cooled even further, the atoms start to "overlap and swallow each other up." This is called coherence.

Again, the fact that a principle as totally counteractive and unexpected as coherence can suddenly appear to mess with previously established knowledge might be considered frustrating—or it could be seen as a delightful reminder of the infinite mystery of the universe.

As Albert Einstein famously demonstrated, light acts like both a wave *and* particles called photons. Light may travel faster than anything else in a vacuum, but other elements have the capacity to slow it down or change its direction. Lasers also manipulate light by artificially limiting where electrons can go when they jump between shells of the atom. The most powerful lasers that exist today can momentarily produce more power than the entire U.S. When they were first introduced in the 1950s, many scientists were deeply skeptical that they would work. However, this skepticism was founded in forgetting the particle/wave "duality of light."

Readers probably have some familiarity with lasers from film and TV, but may not know what they actually are. Lasers are tools that emit light via amplification, which is in turn powered by electronic radiation. Indeed, the word laser was originally an acronym for "light amplification by stimulated emission of radiation."

Contrary to what many people think, Werner Heisenberg's uncertainty principle has almost nothing to do with affecting something simply by looking at it. The principle states that if a particle's precise position is known then it's impossible to precisely know its momentum—and vice versa. This imprecision has nothing to do with bad measurement or observation—it is actually a principle of the physical world. It is always basically impossible to know the location of any single photon inside a beam of light, which is why it *is* possible to precisely channel the energy inside a beam and make it into a laser. Furthermore, quantum physics indicates that on most fundamental and mysterious level, *all* matter behaves much more like a wave than one might assume.

Public misunderstanding of the uncertainty principle shows how once science enters the public imagination via pop culture, mistaken ideas are often the result. Of course, it is unrealistic to expect the average person to have much of a grip on quantum mechanics. At the same time, it is helpful if ordinary people try to avoid falling for sensationalized and misconstrued accounts of science produced by pop culture.

In the 1920s, Satyendra Nath Bose, an Indian physicist, made a mistake while doing quantum mechanics equations in a lecture. Scientific journals refused to publish Bose's findings, however, leaving Bose to resort to sending them to Einstein himself. Impressed, Einstein helped get Bose's research published by placing it at the center a German-language paper he himself then wrote. In this paper, Einstein noticed that in theory, if atoms were cold enough they could condense into a new state of matter. However, at the time, it was technologically impossible to actually make atoms this cold.

The story of Satyendra Nath Bose is both inspirational and infuriating. The fact that the insights of such a brilliant man were discarded based on racism and other forms of prejudice certainly isn't a positive reflection of the scientific community. On the other hand, the fact that his boldness in writing to Einstein paid off again is admirable and inspiring.

The ability to do this came later, via the invention of lasers. Ultimately, Bose and Einstein's theory was proven correct, although the Bose Einstein Condensate only managed to hold together for ten seconds before it combusted. At the same time, laser technology continues to advance. Soon scientists might be able to build "matter lasers" thousands of times more powerful than light lasers and "supersolid" ice cubes could pass through each other *as* solids.

The possible new technologies Kean lists at the end of this chapter may sound outlandish and science fictional, but so would almost all the technology that currently exists today to people in the past.

CHAPTER 17: SPHERES OF SPLENDOR: THE SCIENCE OF BUBBLES

Not every new finding about **the periodic table** takes place under extreme circumstances like in the last chapter. Donald Glaser was a 25-year-old professor at the University of Michigan in 1952. At the time, particle physicists were using information from **the Manhattan Project** to produce zany new particles and some were hoping that these particles "would overthrow the periodic table as the fundamental map of matter." Glaser, meanwhile, was looking at a glass of beer and thinking about how, in liquids, bubbles appear around flaws or anomalies. He began developing ideas of a "bubble chamber" similar to the cloud chambers that already existed for gases. In these chambers, a "gun" fired atoms at cold gas atoms at high speed.

Note here that—although Glaser's story begins with him staring at a perfectly mundane object, a glass of beer—scientists often use terms that have a more specific, technical meaning than their meaning in ordinary life. Neither "bubble" nor "gun" translate directly to how an average person would use them in an ordinary day. Still, they are useful in allowing the reader to create a vivid mental picture of the experiments being performed.

While it's true that Glaser was the inventor of the bubble chamber, the idea that he did so while staring at a glass of beer is myth. However, the myth survives because inside the chamber, Glaser chose beer as the liquid at which to shoot the atomic gun. Sadly, this didn't actually work very well. Glaser had more success with hydrogen, so much so that he ended up winning the Nobel Prize at only 33. Bubbles were not taken seriously as a "scientific tool" for centuries. However, by the time the 20th century arrived, scientists had finally begun to appreciate the special properties and power of bubbles. Indeed, the special role of bubbles in human history would leave one to expect there to be "a long tradition of bubble science," but this is not the case.

The fact that Kean tells the story of Glaser gazing at the glass of beer before then explaining that it's a myth reveals how compelling such myths can be. It also suggests that, even though the story is not true, there is still some value in it. Fictional narratives, folk tales, and legends have their place in science, as in the rest of human culture.

Despite occasional interest from a couple of prominent scientists, bubble science didn't really become a "respectable field" until 1900. Ernest Rutherford and Lord Kelvin were the men who finally got the rest of the scientific community to take bubble science seriously. Rutherford was a New Zealander with a memorable, eccentric personality. After completing graduate school at the University of Cambridge, he took a post in Montreal, picking up where Marie Curie's research had left off. He let pitchblende decay inside a flask, then took bubbles from what remained. These provided samples of radium and polonium, as well as a new element: radon. Conducting further research, he made yet another important discovery: alpha particles are "escaped helium atoms with an early 'neon' light."

Bubble science might appear to be an almost cartoonish and fake-seeming field to those not familiar with it. Perhaps scientists shared this initial suspicion and this is why it took a while for it to become "respectable." However, as this passage shows, not only is it real but highly important and relevant to many different fields of research.

Rutherford announced this new discovery while accepting his 1908 Nobel Prize. He knew that the alpha-helium connection would allow scientists to measure the date of the earth, which for much of history until that point had been calculated via the Old Testament of the Bible. Lord Kelvin (whose full name was William Thomson) had been working on the question of the earth's age for a long time and had eventually come up with the number 20 million years, which was completely wrong. However, a new method for calculating the age of the earth emerged through Rutherford's helium bubble discovery. He began searching for helium bubbles inside rocks, which could then be measured against the rate of radioactive decay in order to come up with an accurate age.

Because of the nonchronological way in which the book is laid out, the reader already knows that Lord Kelvin's estimate about the earth's age is way off, as earlier in the book Kean mentions that Clair Patterson was the first person to make a reasonably accurate guess of the earth's age at 4.55 billion years. (To be slightly more accurate, scientific consensus now puts the figure at 4.543 billion.)

By the time Rutherford found his number, Lord Kelvin was 80 and his mind was no longer sharp. Still, Rutherford worried about disputing the age Kelvin had come up with, although when it came to his actual presentation he managed to do so in a way that flattered the elderly scientist. Nonetheless, Rutherford waited until Kelvin died to prove his helium-uranium hypothesis, announcing that the earth was actually 500 million years old. This, too, was actually wrong, but Rutherford's decision to date the earth using radioactive bubbles was correct and would be the key to humanity finally learning the planet's true age.

Rutherford's decision to wait until Lord Kelvin was dead in order to reveal his findings about the helium-uranium hypothesis and his revised estimate about Earth's age is another example of how social concern can "interfere" with science. However, in this case, Rutherford's act of courtesy was arguably the right decision to make.

Rutherford started a scientific trend of digging from element bubbles inside rocks; it soon became a routine part of a geologist's research. Moreover, this technique was also transposed to other fields, including theoretical physics and quantum mechanics. It came to be known as "froth science," and Lord Kelvin was credited as one of its major pioneers. The field of cell biology also began here, as cells have what is essentially a bubble structure. Years later, a scientist named Seth Putterman was being teased by his colleague at UCLA for not knowing how sound waves transmute bubbles into light. Putterman, who worked in the subfield of fluid dynamics, was shocked to realize that this indeed wasn't available knowledge. He embarked on a series of "low-tech experiments" to discover the truth himself.

"Froth science" is yet another subfield with a humorous name that belies its very serious, complex, and important role. Meanwhile, the fact that cells can in some sense be thought of as bubbles is just one example of why bubble science is so vitally important.

Putterman's research demonstrated an important connection between the nonreactive quality of noble gases and sonoluminescence, the process when a bubble emits short bursts of light when targeted with sonar energy. Putterman himself ended up trying to link his findings to the pathological science of cold fusion, thereby discrediting himself and his work. That aside, bubble science remained an incredibly important scientific mode.

Again, this passage serves as a reminder that even the most brilliant, innovative minds can end up falling for pathological science alongside other false and superstitious beliefs.

CHAPTER 18: TOOLS OF RIDICULOUS PRECISION

National bureaus of standards and measurement tend to attract the most meticulous people alive. There is one in most countries—the U.S. institute is known as the National Institute of Standards and Technology (NIST). The scientists who work at this institution believe that measurement doesn't just facilitate science, but is "a science itself." The global standards bureau—which sets the standards for other bureaus—is located in Paris. The kind of role they are tasked with is, for example, measuring a kilogram to a wildly specific degree. The International Prototype Kilogram housed there must be so precise that it cannot even be scratched or gather a single dust, lest that changes its mass. Ideally, it would not lose "a single atom."

Most non-experts probably assume that precision is important to science, yet few lay people have likely ever thought about how science maintains *this precision. In this chapter, Kean pulls back the curtain, and in doing so, he reminds the reader of the huge amount of effort, care, and near-obsession to detail that characterizes the scientific field.*

The U.S. has its own standard kilogram, which at the time of writing will soon have to be meticulously brought (as hand luggage) to Paris to be measured against the kilogram there. Recently, scientists have been noticing something strange: the Paris kilogram has been losing about half a microgram (equivalent to a fingerprint) of mass per year. No one can explain why. Part of the reason why scientific measurements need to be so exact is so experiments can be replicated as precisely as possible across the world. The fact that the official kilogram is mysteriously shrinking is considered a serious (and embarrassing) problem.

The image of a (perhaps deeply serious) employee from the NIST carrying a special kilogram as hand luggage in an airport is rather comic. However, this passage also brings up an extremely important mystery regarding the kilogram. Again, this interplay of whimsy with a more serious problem emphasizes the wide-ranging human concerns and emotions that often pertain to science.

Somewhat similarly, the length of each Earth day is increasing very gradually, thanks to the effect of the tide on Earth's rotation. In order to adjust to this issue in the most precise way possible, the U.S. has started using an atomic clock, which bases its measurement of time on electrons. The atom they use for the atomic clock is called cesium, which has "heavy, lumbering atoms." While this has led to a standard of precision unlike anything humanity has had before, Kean suggests that there is something poetic lost in no longer relying on the stars and seasons as the tool for measuring time.

The fact that the length of each Earth day is gradually increasing is an important reminder that every form of measurement we have is an invention and an approximation, even if it corresponds to the natural world. No matter how hard people try, it is impossible for humans to ever achieve anything close to a fully precise framework with which to measure the world around us.

"Fundamental constants" refers to pure abstract numbers that never change, like pi or the mass of a kilogram. The "fine structure constant" is a measurement the tightness of the connection between electrons and the nucleus. In the scientific community, it is simply called alpha. This number is extremely important to physicists, because without it atoms couldn't exist. In 1976, a Soviet scientist named Alexander Shlyakhter studied the only organic nuclear fission reactor in the known universe, Oklo, and concluded that alpha was actually getting bigger. For a long time, there was a lot of wild speculation about Oklo, including that it was evidence of a past alien invasion.

The material in this chapter is among the most wacky yet challenging in the whole book, despite—or perhaps because—it concerns some of the most fundamental questions facing humankind. Most nonexperts will likely have never heard of alpha before. Yet it is one of the most fundamental and important principles in the universe.

However, by measuring the elements at the site, scientists were able to see that it was instead simply an extraordinary natural nuclear reactor. Uranium was slowed down by the river water at the site, which allowed reactions to take place where they ordinarily wouldn't have. Studying Oklo, Shlyakhter speculated that the relative lack of samarium produced at the site meant that in the past, alpha must have been ever so slightly smaller. Many scientists have disputed this, unwilling to believe that alpha, a fundamental constant, could change. The debate continues and it will probably be difficult to ever explain the discrepancy at Oklo with absolute certainty.

The fact that a natural nuclear reactor exists is hard to believe—although it's perhaps easier than believing Oklo is the site of a past alien invasion, depending on one's perspective. It is extraordinary that something ordinarily associated with the very latest and most expensive advances in scientific technology has a natural equivalent that was simply waiting to be found.

In the universe, there are black holes called quasars which destroy other stars and in doing so produce light. A group of Australian scientists studied how some ancient quasar light passed through space dust in order to test if it's possible that alpha could have changed. Provocatively, they concluded that the evidence does indeed indicate that alpha may have changed (albeit by only 0.001 percent across 10 billion years). Despite the very low degree by which this change is thought to have taken place, the idea that it might have changed at all has been revolutionary for scientists. If alpha changed, Einsteinian physics would have to be replaced with a totally new paradigm (just as Einstein's theories displaced those of Isaac Newton). It could also transform the search for alien life.

In this passage, Kean finally reveals why the possibility that alpha could be changing, even by only the most mild and gradual degree, is so revolutionary. Indeed, if proven true it would essentially turn the principles of science on their head and lead scientists to have to devise a whole new set of ideas about how the universe operates. However, if this sounds implausible, Kean reminds the reader that it has actually already happened before—when Einstein's theories displaced those of Newton.

Enrico Fermi may have featured some unfortunate incidents—winning a Nobel Prize for a discovery he didn't actually make, dying of beryllium poisoning—but his legacy is a positive one due to the fact that he was the last major scientists who spanned the experimental and theoretical sides of the profession. He had a "devilishly quick mind" and a fondness for posing eccentric questions. However, Fermi was deeply troubled by one of the most fundamental questions facing humanity: considering the size of the universe and the fact that earth is actually a rather ordinary planet, where are the aliens? This question came to be known as "Fermi's paradox."

Even non-expert readers may have heard of Fermi's paradox, which is often cited in the media and popular literature because it so universally fascinating. More than that, it is easy to understand, although this does not mean it is easy to solve.

In 1961, the astrophysicist Frank Drake developed the Drake Equation, which suggested that given the size and properties of the universe, there are about 10 "sociable civilizations" in our galaxy alone. Of course, this is only a guess even if it is based on scientific research. Nowadays, scientists at least know that they don't need to witness civilizations directly through a telescope in order to know they are there. They can use other methods such as searching for magnesium, which is a byproduct of the creation of all life-forms known to humanity.

The Drake Equation is on the one hand useful and thought-provoking, but in another sense totally meaningless. Drake's calculations usefully show how much life humanity should expect to perceive in the universe. Yet considering that humans have no evidence of any other life, surely another explanation is necessary.

The only problem with these methods is that they depend on the notion that the same scientific laws that govern our existence are also true across the universe. If alpha has changed over time, it is possible that earth—despite being unremarkable in many ways—really is unique in having conditions that could produce life. Currently, most scientists don't favor this view, instead maintaining that there are most likely other life-forms in the universe—and probably an enormous number of them. Of course, until a scientist finds proof of alien life, there is simply no way to know for sure.

The question of alien existence might be one of the truly irresolvable scientific problems facing humanity. After all as humans develop further knowledge about the universe and many calculations are made about the likelihood of alien existence, only finding concrete evidence that aliens do *exist will solve the problem (seeing as there is no way to definitively prove that they* don't *exist).*

CHAPTER 19: ABOVE (AND BEYOND) THE PERIODIC TABLE

At the edge of **the periodic table** lie the highly unstable radioactive elements, including francium, which is so reactive that it only ever appears for a moment. There is an even rarer element, though, and finding it requires understanding the "island of stability" and perhaps revising the periodic table completely. Because some elements turn into astatine while undergoing radioactive decay, scientists can guess how much astatine exists in the universe. Strangely, astatine is actually more stable than francium, which is "so fragile it's basically useless." While scientists could never produce a visible study of astatine, a team led by Emilio Segrè did managed to observe it by injecting some into a guinea pig and studying what happened.

Rare elements conjure a certain amount of intrigue in and of themselves, but what makes an element truly exciting or noteworthy to scientists are its properties. In the case of astatine, scientists find it fascinating because it defies how it is logically "supposed" to act based on the laws of the periodic table: instead of being extra fragile, it is extra stable.

One would expect astatine to be even more unstable than francium, but in fact the opposite is true. This is due to the fact that astatine is one of the "magic elements" identified by Maria Goeppert-Mayer—elements that have extra protons or neurons and are therefore much more stable than one would expect. The part of **the periodic table** that contains these counterintuitive elements is called the island of stability. Scientists believe it is unlikely that they will be able to synthesize every element into a magic number by adding particles to the nucleus, but it is definitely possible to do so with at least some. This means that many new elements have yet to be discovered and the periodic table may get a whole lot bigger.

By mentioning Maria Goeppert-Mayer and the magic elements, Kean draws the reader back to where the book began. This journey through many different tangents and tales back to the fundamentals of the periodic table serves as a reminder that everything begins and ends with the elements—they are the foundation of life itself, and of everything in the universe.

These new elements also seem likely to have totally new, unanticipated properties that deviate from the existing rules of **the periodic table**. Over time, Einstein came to distrust quantum mechanics because of its "probabilistic nature." He also failed to coherently unite quantum mechanics with the theory of relativity, despite spending his whole career trying to do so. At the same time, the two theories work well together, and were both needed to discover the element named after Einstein, einsteinium. In other contexts, however, the theories clash. This could place a cap on what is discoverable via the framework of the periodic table.

Einstein is far from the only scientist Kean mentions who changes his mind over the course of his career. Some scientists, like Crookes, come to realize the error of their previous beliefs (i.e., embracing spiritualism) whereas others, like Mendeleev, give up a rational understanding of the world for illogical superstition (refusing to believe in the reality of atoms).

Scientists believe the last element will be 137 (it is provisionally called feynmanium after the physicist Richard Feynman). If elements beyond 137 exist, their electrons would necessarily have to be traveling faster than the speed of light, and the theory of relativity tells us that this isn't possible. Some scientists believe that there is a "loophole" within relativity that allows special particles called tachyons to travel faster than the speed of light. This seems unlikely, though. At the same time, just because element 137 might be the last discovered element doesn't mean that **the periodic table** is simply going to become "fixed and frozen" with no more information added.

The possibility that there are elements past 137—and that there are particles inside atoms traveling at the speed of light—is thrilling. It is suitable that this set of speculative possibilities comes at the end of the book, when Kean can remind the reader of the vast amount of knowledge that still lies waiting to be discovered.

If humans ever come into contact with aliens, the mode of communication most likely to be successful is the "language" of math and physics. At the same time, the version of **the periodic table** humans use now may not correspond to how aliens view the elements. Even from a human perspective, the table is somewhat arbitrary—it could be organized according to a totally different principle, perhaps one much better than the current system. In fact, there are infinite possibilities of what shape the table could take. Scientists have become very creative with these possible shapes, suggesting a solar system-style structure, a double helix, or even a Rubik's Cube. The table could even become three dimensional, with anti-elements represented as well.

The reader has probably already gathered thus far that the periodic table is not a fixed, universal truth, but rather an invented framework for describing things that are true in the universe. Yet just because it responds to physical reality doesn't mean that the periodic table is the only way to represent that reality. There are countless other possible ways, most of which have not even been thought of yet.

Even the ordinary periodic table might be drastically expanded, with new categories of element included. One of these new categories might be elements made of "superatoms." This term refers to the fact that eight to 100 atoms of an element grouped together tend to behave like a single atom, imitating everything a normal, single atom would do to the point that they can be essentially "indistinguishable" from a sole atom. This also means that a superatom made up of one element can act like a totally different element. Matter that does this has been christened "jellium."

Research about superatoms and jellium is at the very cutting edge of the field at the time Kean is writing. For this reason, it still produces more questions than answers, yet it indicates the exciting directions in which the science of the periodic table may be imminently moving.

The periodic table will likely also be revolutionized by quantum dots, which are also called "pancake atoms" because they are completely flat. The pancake periodic table looks very different to the ordinary one, because the atoms inside it behave very differently. Understanding of this phenomenon remains at a very early stage. The important thing to note is that the current iteration of the periodic table is still relevant and will likely be used far into the future. Yet Kean can't help but wish he could fund research into the invention of all kinds of wacky tables. Who knows if one of them would correspond to what a hypothetical alien species has created in order to understand the elements—maybe it could even impress them.

Kean ends on something of a mild paradox. He notes that the current table is still important and relevant and will be useful to scientists long into the future. At the same time, he feels impatient about the other kinds of tables that could be invented to represent the elements. Perhaps soon there will be multiple tables coexisting at once, each serving a different purpose—and one of those purposes could even be trying to impress aliens.

HOW TO CITE

To cite this LitChart:

MLA

Seresin, Indiana. "*The Disappearing Spoon.*" *LitCharts*. LitCharts LLC, 6 Feb 2020. Web. 21 Apr 2020.

CHICAGO MANUAL

Seresin, Indiana. "*The Disappearing Spoon.*" LitCharts LLC, February 6, 2020. Retrieved April 21, 2020. https://www.litcharts.com/lit/the-disappearing-spoon.

To cite any of the quotes from *The Disappearing Spoon* covered in the Quotes section of this LitChart:

MLA

Kean, Sam. The Disappearing Spoon. Back Bay Books. 2011.

CHICAGO MANUAL

Kean, Sam. The Disappearing Spoon. New York: Back Bay Books. 2011.