The Double Helix

INTRODUCTION

BRIEF BIOGRAPHY OF JAMES D. WATSON

James Watson was born and raised in Chicago, where he developed an early passion for birdwatching and ornithology. He began studying at the University of Chicago at just 15 years old and graduated with a degree in Zoology in 1947. He then took an interest in the growing field of genetics, and he went to pursue a PhD at Indiana University. He finished in 1950, then moved to Europe to begin his career as a researcher. *The Double Helix* covers the next three years: Watson began by researching bacteriophages in Copenhagen, then moved to the University of Cambridge, where he and Francis Crick famously used Rosalind Franklin's X-ray data to discover the double helix structure of DNA. This discovery revolutionized molecular biology and is the foundation for all modern work in genetics. In 1956, Watson moved to Harvard University's Department of Biology, and in 1962, he shared the Nobel Prize in Physiology or Medicine with Francis Crick and Maurice Wilkins. Then, in 1968, he joined the prominent Cold Spring Harbor Laboratory (or CSHL) as its research director. He stayed at the CSHL for three decades, helping it greatly expand and become a world leader in medical and genetic research. He briefly led the Human Genome Project from 1990-1992, but left after refusing to condone the National Institutes of Health's plan to patent human genomes. He then returned to the CSHL. Ever since the mid-1990s, Watson has largely gained public attention for pushing the widely-disproven idea that Black people are less intelligent than white people because of genetic differences. He has also blamed genetic inferiority for women's underrepresentation in science and argued that research is more effective without them. The scientific community has widely condemned his views. The CSHL fired him from his leadership position because of his racist comments in 2007, and then publicly denounced and cut all ties with him after he repeated these comments in 2019. In response to the public outcry over his beliefs, Watson complained of being treated as an "unperson" and denied opportunities. He also insisted that he is "not a racist in a conventional way." He even became the first Nobel laureate to auction off his Nobel Prize in 2014.

HISTORICAL CONTEXT

Crick and Watson discovered the structure of DNA in the early 1950s, a time of profound scientific and political change. During World War II, scientific research started to play a greater role in public affairs than ever before. This process only accelerated during the Cold War, as the U.S. and Soviet Union began competing for scientific dominance—especially in physics, space, and weapons research. With the end of World War II suddenly freeing up significant state resources, governments in the U.S. and Europe also poured unprecedented funding into research of all kinds. Yet while science shaped both World War II and the Cold War, these events also deeply shaped scientists themselves. Many of the scientists who figure prominently in *The Double Helix*—including Francis Crick, Maurice Wilkins, and Max Delbrück—actually switched from physics to biology after World War II. In part, they were disillusioned to see physics put to such destructive uses during the war, and they hoped that biology could do more good than harm. Meanwhile, Cold War politics were also starting to seriously restrict academic freedom on both sides of the Iron Curtain. Watson notes how the U.S. government prevented renowned scholars like Salvador Luria and Linus Pauling from traveling to Europe for conferences because of their peace activism. While Crick and Watson were somewhat insulated from both of these trends at Cambridge, they clearly saw how science's role in society was shifting in the early 1950s: it was growing more powerful, but also closer to the state. In particular, they also saw the great potential in genetics and molecular biology. While the monk Gregor Mendel laid the foundations for modern genetics in the 1860s, the field did not grow significantly until the early 1900s. By the 1940s, new results were revolutionizing the field almost every year. Many of these results—like Oswald Avery's experiments on bacteria—were crucial to getting scientists like Watson and Crick to pay attention to DNA, which was first discovered in 1869 but largely ignored until the mid-1940s. In turn, Watson and Crick's discovery of the double helix structure was by far the most significant finding in genetics in the 20th century. It not only revolutionized scientists' understanding of heredity, but also allowed them to identify and study specific genes, which enabled innovations like gene sequencing.

RELATED LITERARY WORKS

Besides *The Double Helix*, James Watson's best-known books are likely the textbooks *Molecular Biology of the Gene*, *Molecular Biology of the Cell*, and *Recombinant DNA*. (All have gone through several editions.) His memoir, *Avoid Boring People and Other Lessons from a Life in Science* (2007), and his popular introduction to genetics, *DNA: The Secret of Life* (2003), are also widely read. In *The Double Helix*, Watson mentions two important books that he frequently consulted during his research: Linus Pauling's *The Nature of the Chemical Bond* (1939) and J.N. Davidson's *The Biochemistry of Nucleic Acids* (1950). Moreover, as Watson points out in his book, his collaborators are all prominent scientists with stories of their own. Most importantly, ever since Rosalind Franklin's death in

1958, scholars have paid significant attention to her overlooked place in the search for DNA. The most significant book about Franklin is her close friend Anne Sayre's *Rosalind Franklin and DNA* (1975), which was in part a response to Watson's highly critical portrayal of Franklin in *The Double Helix*. Brenda Maddox has also written an influential biography of Franklin, *Rosalind Franklin: The Dark Lady of DNA* (2002). Francis Crick's books include *What Mad Pursuit: A Personal View of Scientific Discovery* (1988) and *Of Molecules and Men* (2004), while Maurice Wilkins published an autobiography, *The Third Man of the Double Helix* (2003). Linus Pauling also published several books, but the science writer Thomas Hager has written the three most widely-read works about his life: *Force of Nature: The Life of Linus Pauling* (1995), *Linus Pauling and the Chemistry of Life* (1998), and *Linus Pauling: Scientist and Peacemaker* (2001). Finally, the most detailed, authoritative history of Crick and Watson's research is Robert Olby's *The Path to the Double Helix: The Discovery of DNA* (1994).

KEY FACTS

- **Full Title:** The Double Helix: A Personal Account of the Discovery of the Structure of DNA
- **When Written:** 1961-68
- **Where Written:** Carradale, Scotland; Cambridge, Massachusetts, United States
- **When Published:** 1968
- **Literary Period:** 20th-century scientific nonfiction
- **Genre:** Memoir, Narrative Nonfiction, Popular Science
- **Setting:** The Cavendish Laboratory at the University of Cambridge, England; also London, Paris, Copenhagen, and Naples
- **Climax:** James Watson and Francis Crick discover and build an accurate model of DNA as a double helix with complementary bases.
- **Point of View:** First-person memoir

EXTRA CREDIT

Researchers' Responses. Many of Watson's collaborators strongly objected to him publishing this book—including Francis Crick, Maurice Wilkins, and Sir Lawrence Bragg. Crick reportedly called the book "a violation of friendship" and "a contemptible pack of damned nonsense." While Bragg eventually changed his mind and agreed to write the book's introduction, these objections led Harvard University Press to drop it.

PLOT SUMMARY

In his memoir *The Double Helix*, the influential but controversial molecular biologist James D. Watson recounts how he and Francis Crick discovered the structure of DNA at the University of Cambridge in 1953. This discovery was remarkable not only because it revolutionized genetics forever, but also because Watson and Crick were young and completely unknown when they made it: Watson was only 25 years old, and Crick, while much older, hadn't even finished his PhD. In *The Double Helix*, Watson explains how a combination of input from other scientists, creative theorizing, and youthful ambition led him and Crick to the "key to the secret of life."

Watson prefaces his book by emphasizing that he is merely presenting his own memory of events as he experienced them—and not the absolute truth. He also briefly reflects on the dynamism and intensity of his years at Cambridge. Then, he begins his first chapter by declaring, "I have never seen Francis Crick in a modest mood." He remembers Crick's boisterous personality and endless curiosity, which often led him to spend his days theorizing about other people's data instead of doing his doctoral research on protein structure. In fact, while Crick's colleagues at the Cavendish Laboratory were trying to understand the secrets of life and heredity by studying proteins, Crick belonged to the growing minority of biologists who thought that genes were really made of DNA. So did Watson.

The one man in England who took DNA seriously was Crick's friend Maurice Wilkins, who tried to understand its structure through a crystallography technique called X-ray diffraction. However, Wilkins's research advanced slowly because of his constant quarrels with his strong-willed assistant Rosalind Franklin. Watson saw Franklin as too independent, curt, and plainly dressed for a woman in science. In fact, he thought that Wilkins should have fired her at once. However, to truly understand Watson's sexist remarks about Franklin, readers must know that he left a crucial truth out of the story: in reality, Franklin wasn't Wilkins's assistant at all, but rather his colleague and equal.

Watson first learned about Maurice Wilkins's research at a conference in Naples in 1951. He had just finished his PhD in Indiana and moved to Copenhagen on a fellowship. Although Watson was supposed to be studying DNA under the biochemist Herman Kalckar, he couldn't stand Kalckar's methods, personality, or incomprehensible accent. Therefore, he started working with the phage researcher Ole Maaløe while he looked for another direction to take his research. When he went to Naples and saw Maurice Wilkins's X-ray photo of DNA, he realized that he needed to go to England and study crystallography. He secured a place working with Max Perutz at the Cavendish Laboratory at Cambridge. While he waited to see if he could transfer his fellowship there, he moved in with Perutz's collaborator John Kendrew and lived off his savings. That's when he met Francis Crick.

Crick and Watson were fast friends: they started eating their meals together and spending their days talking about every scientific topic under the sun. Both were intensely interested in DNA. Crick told Watson about how Linus Pauling discovered the alpha helix protein structure using special **molecular models**, and the pair started wondering if they could use the same process to build a model for DNA. Crick and his colleague Bill Cochran developed a new theory of how to detect helix shapes through X-ray diffraction, and then Watson learned about Rosalind Franklin's X-ray diffraction results at one of her talks. By combining Crick's new theory with Franklin's data, Crick and Watson theorized that DNA could be a three-strand helix with each strand's sugar-phosphate backbone in the middle and its nitrogenous bases pointing outwards. They built a model of this hypothetical model, and then invited Maurice Wilkins, Rosalind Franklin, and their graduate students to visit Cambridge and take a look.

But Wilkins and Franklin's visit was a catastrophe: they found a series of fatal flaws in Crick and Watson's model. Worse still, Watson realized that he misquoted Franklin's data to Crick, so their theory was based on the wrong numbers. Crick and Watson discarded their model, and the Cavendish Lab's leader, Sir Lawrence Bragg, furiously ordered them to stop working on DNA. They agreed. Watson started doing X-ray diffraction experiments with tobacco mosaic virus, while Crick went back to his PhD research on protein structure.

But Crick and Watson continued to follow other scientists' research on DNA. American researchers showed that viruses use DNA to infect bacteria, while the biochemist Erwin Chargaff discovered a pattern in DNA's four nitrogenous bases: there tends to be exactly as much adenine as thymine and exactly as much guanine as cytosine. Crick and the theoretical chemist John Griffith determined that adenine and thymine could probably bond together, as could guanine and cytosine. Watson and Crick met Chargaff and explained their findings, but Chargaff dismissed the pair as inexperienced and overconfident. At a major conference in Paris a few weeks later, Watson also met the world-famous Linus Pauling, who was reportedly working on DNA.

That fall, Crick tried to convince Watson to drop his new research on bacterial mating and take another look at DNA. At first, Watson was hesitant. Linus Pauling's son Peter came to Cambridge to pursue his PhD, and he initially reported that his father wasn't working on DNA at all. But soon, this changed: Linus Pauling sent a letter to Peter, explaining that he had discovered the structure of DNA. Crick and Watson were astonished and disheartened all at once. But then, Pauling sent in a copy of his proposal: it looked just like the model that Crick and Watson showed Maurice Wilkins and Rosalind Franklin. It was dead wrong, and Crick and Watson could prove it. In fact, it was based on a basic chemistry error.

After Pauling's blunder, Crick and Watson agreed that it was time to give DNA another shot. Pauling would soon realize and correct his mistake, so if Crick and Watson wanted to discover DNA's structure before Pauling did, they had to act immediately.

Watson visited Maurice Wilkins to tell him about Pauling's mistake, but got in an argument with Rosalind Franklin instead. After Watson and Franklin's argument, Wilkins showed Watson one of Franklin's secret X-ray diffraction images. Watson was stunned: Franklin's diffraction picture clearly showed that DNA had a helical structure. As soon as he got back to Cambridge, Watson got permission to work on DNA with Crick. They immediately started putting together a new model, but for several days, they didn't make much progress.

Then, one day, Watson remembered that the nitrogenous bases in DNA—adenine, thymine, guanine, and cytosine—are all capable of forming hydrogen bonds with themselves. This meant that DNA could look like a corkscrew-shaped ladder: it would have two strands, with the sugar-phosphate backbones on the outside and the nitrogenous bases of each nucleotide pointing inward. Each of the two strands would have an identical sequence of nitrogenous bases, and hydrogen bonds between these bases would hold the DNA molecule together.

Watson briefly thought he had solved the puzzle of DNA, but he soon realized that this structure wouldn't work. Since all the nitrogenous bases were different sizes, a DNA molecule would be irregularly-shaped, full of random bulges and indentations. That wasn't possible.

Two days later, however, Watson realized that, when adenine bonds to thymine, they form a combination with exactly the same shape as the combination of guanine bonded to cytosine. This meant that the DNA molecule could have an irregular sequence of nitrogenous bases *and* a perfectly regular shape. When Watson told Crick about his idea, Crick was immediately convinced. At lunch, he started telling everyone that he and Watson had discovered "the secret of life." Watson and Crick built a new model of **the double helix structure**, measured it to make sure it was exactly right, and then showed it to their mentors and colleagues. Everyone who learned about their model was convinced—including Rosalind Franklin and even Linus Pauling. Crick and Watson published their results in the journal *Nature*, and their discovery went on to transform biology forever.

CHARACTERS

MAJOR CHARACTERS

James D. Watson – The author of *The Double Helix* is a prominent but controversial Nobel Prize-winning geneticist and molecular biologist. He is still best known for discovering **the double helix structure** of DNA with Francis Crick. From 1950 to 1953, the years covered in this book, Watson was a totally unknown researcher in his early twenties, working on postdoctoral fellowships in Europe. Although he did his PhD research on bacteriophages with Salvador Luria at Indiana University, by 1950 he was far more interested in the structure and function of DNA. While most scientists still saw proteins as the key to understanding genetics, an important minority—including Watson, Crick, and Luria—focused on DNA. The book begins with Watson's time in Copenhagen, then follows him to the Cavendish Laboratory at Cambridge, where he studied DNA, bacteria, and viruses under Max Perutz, Sir Lawrence Bragg, and Roy Markham. Besides his research, he spent much of his time studying biochemistry and crystallography, traveling around Europe, and chasing women at Cambridge. Even though Crick and Watson's initial attempts to model DNA were spectacular failures, they eventually discovered the double helix structure in early 1953. Watson presents his insight about the hydrogen bonds between adenine, thymine, guanine, and cytosine as the key to discovering the double helix. However, he also notes that this discovery relied heavily on other scientists' work, including Maurice Wilkins and Rosalind Franklin's extensive research on DNA, Erwin Chargaff's work on nitrogenous bases, and Linus Pauling's discoveries about molecular structure. They also received important pointers from colleagues like John Griffith and Jerry Donohue. Watson emphasizes that he chose to write this book from the perspective of his younger self, and he promises that he is presenting his own personal views, and not the definitive truth about the search for DNA. Still, his life and work remain incredibly controversial, particularly because of his portrayal of Rosalind Franklin, his decision to publish this book despite Francis Crick and Maurice Wilkins's opposition, and his long history of offensive comments.

Francis Crick – Francis Crick was the prominent, Nobel Prize-winning English molecular biologist and neuroscientist who is best known for discovering **the double helix structure** of DNA with James Watson in 1953. Watson portrays Crick as talkative, irreverent, and brilliant. This combination of traits alienated some people, but entranced others—including Watson. When they first met in 1951, Crick and Watson instantly connected, both because of their personalities and because of their shared interest in DNA. They quickly became research partners and very close friends. They often ate lunch together, and Watson frequently went to Crick's home for dinner because his wife Odile was a superb cook. (According to Watson, she also didn't mind her husband's affairs with younger women.) Curiously, when they met, Watson was a 22-year-old postdoctoral researcher, while Crick was a 35-year-old graduate student—after switching from physics to biology during World War II, he still hadn't finished his thesis. The Cavendish Lab's director, Sir Lawrence Bragg, blamed Crick's slow progress on his tendency to distract himself with theory: he spent more time talking to other scientists and trying to interpret their experimental results than actually doing his own research. True to form, from 1951 to 1953, Crick was supposed to be studying proteins but actually spent much of his time trying to work out the structure of DNA with Watson. While this repeatedly landed them in trouble and embarrassed their bosses, it ultimately paid off—they discovered the double helix structure using molecular models in 1953. Crick's outgoing personality ultimately proved to be an important asset in the search for DNA: he frequently called on the expertise of his wide circle of friends in the scientific community.

Rosalind Franklin – Rosalind Franklin was a pioneering crystallographer and chemist who studied DNA through X-ray diffraction. Her X-ray data enabled Crick and Watson to discover **the double helix structure** of DNA. However, they obtained this data without her permission or knowledge. Watson consistently portrays Franklin as highly competent but also humorless, self-important, and even aggressive. According to Watson, Franklin refused to cooperate with other scientists and constantly fought with her colleague Maurice Wilkins. Watson also claims that Franklin refused to use **molecular models** in her research and rejected the idea that DNA could be helical in structure. Based on these claims, Watson strongly implies that Franklin never would have discovered the double helix structure on her own. In turn, this paints Watson and Crick's unethical behavior as a necessary evil. Needless to say, this is all highly controversial: numerous scientists, historians, and literary critics have denounced Watson's portrayal of Franklin as extremely misogynistic and unfair, even by the standards of his time. For instance, Watson constantly comments on Rosalind Franklin's appearance: he thought she should dress more carefully, do her hair differently, and wear makeup in order to impress men. Many of Watson's claims about Franklin are also simply inaccurate. He calls her "Rosy," a nickname the real Rosalind Franklin never used. He frequently complains about her glasses, even though the real Rosalind Franklin didn't wear glasses. Finally, he characterizes her as Maurice Wilkins's insubordinate assistant, even though the real Rosalind Franklin was actually Wilkins's equal, an independent researcher with her own team and projects. Thus, while this book reveals little about the actual Rosalind Franklin, the "Rosy" who does appear in it reveals plenty about Watson's prejudices and attitude towards his own unethical conduct.

Maurice Wilkins – Maurice Wilkins was a Nobel Prize-winning biophysicist who performed important X-ray diffraction experiments on DNA. Wilkins and Rosalind Franklin's lab at King's College London was one of three doing this kind of work in the early 1950s, along with Linus Pauling's lab at Caltech and the Cavendish Laboratory at Cambridge. Wilkins was also one of the first researchers to understand DNA's potentially transformative role in genetics, and he worked on it longer than anyone else, starting in 1948. In fact, Wilkins's X-ray images first inspired Watson to move to England, learn about crystallography, and study the structure of DNA. Careful, soft-spoken, and extremely reserved, Wilkins was in many ways the opposite of his talkative, energetic friend Francis Crick. Between 1951 and 1953, he also befriended Watson, as they met frequently to discuss their DNA research. Controversially, Watson suggests that Wilkins frequently complained about Rosalind Franklin at these meetings, but his true feelings about her are difficult to ascertain. Ultimately, Wilkins gave one of Franklin's X-ray images of DNA to Crick and Watson—and this image ultimately enabled them to discover **the double helix structure**. While Watson doesn't address the ethical implications of taking Franklin's data, he does acknowledge that it may have been socially unacceptable for him and Crick to research the same topic that Wilkins had already been working on for several years. In fact, Watson even argues that Wilkins deserved the first shot at DNA's structure. Instead, Wilkins began modeling DNA's structure with **molecular models** at almost exactly the same time as Crick and Watson discovered the double helix.

Linus Pauling – Linus Pauling was a prominent American chemist, molecular biologist, writer, and activist. He won two Nobel Prizes, one for his scientific research and one for his activism against nuclear proliferation. In the mid-20th century, he was an international celebrity and perhaps among the most famous scientists in the world. He also faced significant persecution for his political views: the U.S. government briefly revoked his passport in 1952, and the trustees of Caltech pressured him into leaving his position as the Chemistry and Chemical Engineering Department chair in 1963. Pauling was an expert on chemical bonds, and he pioneered the use of X-ray diffraction crystallography and **molecular models** to study the structure of key macromolecules like proteins and DNA. Pauling's lab at Caltech and Sir Lawrence Bragg's lab at Cambridge were the two major players in this area of research, and they enjoyed an intense but healthy rivalry. In fact, Pauling's discovery of the alpha helix structure in proteins inspired Crick and Watson to look for a helical structure in DNA. In late 1952 and early 1953, Crick and Watson were racing to discover DNA's structure before Pauling, who was likely only a few days or weeks behind them. Meanwhile, Pauling's son Peter was doing his PhD alongside Crick and Watson in the Cavendish Lab. Ultimately, Pauling proposed an incorrect structure for DNA shortly before Crick and Watson got it right. But he responded to their discovery with sincere congratulations and "genuine thrill." While Crick and Watson's rivalry with Pauling drives their research forward in the second half of *The Double Helix*, it also raises significant ethical questions about data sharing and the attribution of ideas in modern science.

Sir Lawrence Bragg – Sir Lawrence Bragg was the internationally renowned, pioneering crystallographer and physicist who ran the Cavendish Laboratory from 1938 to 1953. He won the Nobel Prize in 1915 at just 25 years old, making him by far the youngest Nobel laureate ever in the sciences. Bragg laid the foundations for modern X-ray diffraction crystallography and supervised Crick and Watson when they used Rosalind Franklin's X-ray data to discover **the double helix structure** of DNA. He also oversaw the research of Max Perutz, John Kendrew, and many of the other central figures in *The Double Helix*. Honest, serious, and "uncompromisingly British," Bragg couldn't stand Francis Crick's boisterous personality and frequently clashed with him. However, Brigg also cared deeply about his lab's reputation and was preoccupied with beating his main rival, the American chemist Linus Pauling, to key discoveries (like the structure of DNA). Thus, after Crick and Watson's great discovery, Bragg became one of their most enthusiastic supporters.

Erwin Chargaff – Erwin Chargaff was an influential biochemist who conducted many influential early studies on DNA. In fact, he was one of very few scientists who thought DNA—and not proteins—were responsible for heredity before the 1950s. Chargaff strongly disliked Watson and Crick when he met them over dinner in Cambridge, but his results played a crucial role in their quest for the structure of DNA. Namely, Chargaff discovered DNA generally has the same amount of adenine as thymine and guanine as cytosine. This finding led Watson to the realization that these pairs of nitrogenous bases could bond together—which led him directly to **the double helix structure**. Thus, Chargaff's research into DNA laid the foundation for Crick and Watson's discovery.

Max Delbrück – Max Delbrück was a prominent biophysicist who frequently collaborated with Salvador Luria on phage research, but also worked alongside Linus Pauling at Caltech in the early 1950s. Because of his connections to both Luria and Pauling, he became one of Crick and Watson's most important advisors during their final push to study the structure of DNA in early 1953. He was also the first to break news of their discovery to the American scientific community.

Jerry Donohue – Jerry Donohue was an American chemist and crystallographer who worked in the Cavendish Laboratory. When Watson hypothesized that DNA's two strands could have the same sequence of nitrogenous bases, Donohue pointed out that Watson's model was based on the wrong molecular structures for guanine and thymine. Watson emphasizes his debt to Donohue—without whom Watson and Crick would have never discovered **the double helix structure**.

Herman Kalckar – Herman Kalckar was a prominent Danish biochemist who studied DNA in the early 1950s. Watson's postdoctoral fellowship was intended to fund him to work in Kalckar's lab and learn about biochemistry. However, Watson found Kalckar boring, indifferent, and impossible to understand. As a result, he spent the rest of his time in Copenhagen studying phages in Ole Maaløe's lab instead.

Peter Pauling – Peter Pauling was a prominent crystallographer and the son of world-renowned chemist Linus

Pauling. In 1952, Peter began his PhD research at the Cavendish Lab and quickly befriended James Watson. Their conversations revolved around two things: women and the state of Peter's father's research. In the spirit of friendship and scientific openness, Peter shared his father's letters with his colleagues. This is how Crick and Watson learned about Linus Pauling's research on DNA. In fact, Crick and Watson returned to DNA research at the beginning of 1953 in large part because they wanted to discover its structure before Pauling. Therefore, Peter's letters arguably played a pivotal role in Crick and Watson's success: if Peter hadn't tipped them off, Linus Pauling might have beat them to the double helix. Thus, Crick and Watson's relationship with Peter Pauling raises many of the same thorny ethical questions as their collaboration with Maurice Wilkins and Rosalind Franklin.

Max Perutz – Max Perutz was the influential, Nobel Prize-winning Austrian molecular biologist and crystallographer who ran the Molecular Biology Unit at the Cavendish Laboratory starting in the mid-1940s. As Crick and Watson's research supervisor, Perutz frequently consulted with them about their progress and intervened to keep them out of administrative trouble (especially with Sir Lawrence Bragg). Controversially, he also helped Crick and Watson access Rosalind Franklin's unpublished data, which they used to build their model of DNA.

Willy Seeds – Willy Seeds was Maurice Wilkins's research partner at King's College London. He visited Cambridge to see Crick and Watson's unsuccessful first model of DNA, and several years after the book's events, he ran into Watson in the Swiss Alps and asked him, "How's Honest Jim?" (This was a sarcastic reference to Crick and Watson stealing Rosalind Franklin's X-ray diffraction data.)

Elizabeth Watson – Elizabeth Watson was James Watson's sister. She frequently visited him throughout his time in Copenhagen and Cambridge—where she stayed during the final months of Crick and Watson's research into the double helix structure. Watson's narration shows that he clearly loves his sister, but his description of her also focuses exclusively on her appearance and love life, suggesting that traditional gender norms strongly influenced Watson's thinking in the 1950s and 1960s.

MINOR CHARACTERS

John Kendrew – John Kendrew was a Nobel Prize-winning crystallographer and biochemist who was also Max Perutz's main research partner at the Cavendish Laboratory. He was one of Watson's most important mentors at Cambridge. In fact, Watson lived with Kendrew and his wife Elizabeth throughout his time there.

Salvador Luria – Salvador Luria was the Nobel Prize-winning microbiologist and phage researcher who supervised Watson's thesis. During Watson's time in Europe, Luria helped him find research funding and connect with other scientists. The U.S. government also banned him from international travel for his peace activism.

J.D. Bernal and I. Fankuchen – Bernal and Fankuchen were crystallographers who conducted important X-ray diffraction experiments on tobacco mosaic virus (TMV).

Odile Crick – Odile Crick was Francis Crick's wife and an internationally renowned artist. Watson portrays her as loving, conventional, and ignorant about science—but also suggests that this is how scientists' wives ought to be.

Bill Cochran – Bill Cochran was a Scottish crystallographer who worked at the Cavendish Laboratory. He and Francis Crick developed an innovative new method to study helical molecules through X-ray diffraction. This method helped Crick and Watson interpret Rosalind Franklin's X-ray data and identify that DNA is helical.

Bertrand Fourcade – Bertrand Fourcade was an attractive, popular French exchange student who dated Watson's sister Elizabeth.

R.G. Gosling – Raymond George (R.G.) Gosling was a graduate student who worked under Rosalind Franklin in the lab that she and Maurice Wilkins shared at King's College London.

John Griffith – John Griffith was a theoretical chemist and friend of Francis Crick at Cambridge. His calculations showed Crick and Watson that adenine could bond with thymine and guanine could bond with cytosine.

Bill Hayes – Bill Hayes was an Irish geneticist who studied bacterial mating during Watson and Crick's time at Cambridge.

Dorothy Hodgkin – Dorothy Hodgkin was a Nobel Prize-winning chemist and pioneering crystallographer at Oxford.

Hugh Huxley – Hugh Huxley was Francis Crick's close friend and John Kendrew's graduate student. He studied muscle fibers and taught Watson how to do X-ray diffraction experiments.

Ole Maaløe – Ole Maaløe was a Danish phage researcher with whom Watson worked extensively during his time in Copenhagen (although he was supposed to be working under Herman Kalckar instead).

Roy Markham – Roy Markham was a biochemist at Cambridge who specialized in studying plant viruses. He helped Watson get his fellowship transferred to Cambridge and supervised some of Watson's work on TMV.

Avrion Mitchison – Avrion Mitchison was one of Crick and Watson's friends at Cambridge. He invited Watson to his family home in Scotland one Christmas. In fact, a decade later, Watson also wrote most of this book at Mitchison's house.

TERMS

Adenine, Thymine, Guanine, and Cytosine – Adenine, thymine, guanine, and cytosine (generally labeled A, T, G, and C) are the four nitrogenous bases that occur in DNA and carry an organism's genetic code.

Alpha Helix – The alpha helix is a common molecular structure in proteins, which **Linus Pauling** discovered in 1951. It involves a series of amino acids (or polypeptide chain) arranged in a twisting, helical structure. Pauling's research on the alpha helix strongly influenced **Crick** and **Watson**'s research into DNA.

Bacteriophages (Phages) – Bacteriophages, or *phages* for short, are viruses that infect bacteria. **Watson** began his research career by studying bacteriophages.

Cambridge Colleges – The University of Cambridge is composed of several dozen smaller colleges that provide accommodation, community, and undergraduate teaching for students.

Cavendish Laboratory – The Cavendish Laboratory is the prominent laboratory at the University of Cambridge where **Watson** and **Crick** conducted their research in the early 1950s and discovered DNA's double helix structure.

Crystallography – Crystallography is the study of the structure of crystals (including crystallized biological molecules, like DNA). The most important crystallography technique is X-ray diffraction.

DNA – Deoxyribonucleic acid, or DNA, is the molecule that carries an organism's genetic code. Before **Crick** and **Watson** discovered its double helix structure in 1953, however, scientists didn't understand its purpose and strongly disagreed about its importance. DNA is made of a chain of nucleotides, each of which consists of a phosphate group, the sugar deoxyribose, and a nitrogenous base (adenine, thymine, guanine, or cytosine) that encodes genetic information.

Hydrogen Bonds – A hydrogen bond is the weak attractive force between a hydrogen atom in one molecule and the negatively-charged atoms in another molecule (like the oxygen atom in a water molecule). Hydrogen bonds hold together DNA's two strands by weakly linking their complementary nitrogenous bases.

Nitrogenous Bases – Nitrogenous bases are the component of DNA's nucleotides that encodes genetic information. DNA includes four nitrogenous bases—adenine, thymine, guanine, and cytosine—which are attached to the sugar-phosphate backbone.

Nucleotide – Nucleotides are the basic components of DNA. In fact, DNA is just a very long chain of nucleotides. Each nucleotide consists of three components: the sugar deoxyribose, a phosphate group, and a nitrogenous base. Each nucleotide's phosphate group binds with the next nucleotide's sugar component, which forms the sugar-phosphate backbone in DNA. Meanwhile, each nucleotide's nitrogenous base (adenine, thymine, guanine, or cytosine) makes up one element of an organism's genetic code.

Phosphate Groups – The phosphate group is one of the three components of a nucleotide in DNA. Phosphate groups bond with the sugar deoxyribose to form a DNA molecule's sugar-phosphate backbone.

Polypeptide Chain – A polypeptide chain is a series of amino acids that are bonded together and form a protein.

Sugar-Phosphate Backbone – The sugar-phosphate backbone is the chain of alternating phosphate groups and deoxyribose sugars that holds together a series of different nucleotides. DNA has two sugar-phosphate backbones, which wrap around each other in a helical structure and hold the molecule together.

Tobacco Mosaic Virus (TMV) – Tobacco mosaic virus (or TMV for short) is a common plant virus. It was the first virus ever discovered, and it's frequently used in scientific research because it's easy to produce and poses no danger to humans. **Watson** briefly studied TMV and used X-ray diffraction to show that it has a helical structure.

X-ray Diffraction – X-ray diffraction is an important technique in crystallography. It involves shooting an X-ray beam at a crystal, then measuring how this X-ray beam diffracts (or splits apart in different directions). These diffraction measurements allow crystallographers to determine where different atoms are located inside the crystal. **Rosalind Franklin**'s X-ray diffraction experiment on DNA gave **Crick** and **Watson** the key measurements they needed to model the double helix structure.

THEMES

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RESEARCH, ADVENTURE, AND THE THRILL OF DISCOVERY

The Double Helix is biologist James D. Watson's memoir about his life and work from 1950 to 1953, the year when he and Francis Crick discovered the structure of DNA. Although the book focuses on biological research and largely takes place in a laboratory, it's by no means a dry summary of scientific concepts, experiments, and results. Instead, it reads more like a detective thriller. When Crick and Watson started studying DNA, they were young, unknown researchers in the Cavendish Laboratory at the University of Cambridge. Although they dreamt of cracking the DNA code, they didn't even know the basics of organic chemistry. Their unconventional methods frustrated and embarrassed their bosses, who ordered them to put DNA aside. But they kept studying it in secret, hoping to model its structure before the world-renowned chemist Linus Pauling could. Against all odds, they succeeded. By humanizing the race for DNA, *The Double Helix* defies ordinary depictions of scientific research and the people who do it. Watson shows that science isn't a straightforward, linear process of knowledge accumulation, but rather a dramatic, unpredictable process of trial and error driven by the fundamental human desire for meaning, adventure, and glory.

Watson and Crick became researchers because science appealed to their deep emotional needs: their curiosity, daring, and sense of pride. In the first chapter of his book, Watson notes that Crick was a sort of black sheep at the Cavendish Laboratory. He was 35 years old and still working on his PhD, but he spent most of his time coming up with new theories based on other people's research. Watson writes that whenever Crick had a new idea, he "would become enormously excited, and immediately tell it to anyone who would listen." Crick's enthusiasm for knowledge reveals that his fundamental motivation for becoming a scientist was his overwhelming urge to make sense of the world. Watson took a similar path to the Cavendish Laboratory: he ignored his obligations and followed his curiosity instead. In 1950, he was supposed to be living in Copenhagen, doing research with the biochemist Herman Kalckar. But Kalckar's work didn't interest Watson, so he simply left and went to Cambridge instead. For his first year there, he worked for nothing, living off his savings. Thus, curiosity fundamentally motivated both Crick and Watson's research agendas. But they were also hooked on the high stakes of DNA research, which appealed to their need for adventure. When they started in 1951, nobody knew for sure whether genes were encoded into DNA, so Crick and Watson knew that they were entering uncharted territory. Watson and Crick also knew that, if they kept trying and failing to model DNA, they could lose their funding (and even their entire academic careers). But if their experiments succeeded, they could achieve international fame. In fact, Watson admits that he hoped to become famous by making a major discovery. He and Crick particularly wanted to discover DNA's structure before Linus Pauling could, which shows that their sense of pride and self-importance also motivated their research.

Because the scientific method is a messy, human process—and not a predictable or automatic one—Crick and Watson's attempts to model DNA turned into a thrilling, all-consuming quest for the truth. Crick and Watson began studying DNA against their better judgment: Crick was supposed to be finishing his PhD research, while Watson was supposed to be researching viruses, and their bosses frequently reminded them to stay on task. They had neither the knowledge nor the experience necessary to study DNA, and they knew that they risked offending Maurice Wilkins, who was doing similar research only an hour's train ride away in London. But Crick and Watson couldn't stop thinking about the DNA structure, so they pursued it anyway. This approach initially led them to catastrophe. When they thought they had the structure figured out, they spent a day explaining their theory to Maurice Wilkins and Rosalind Franklin—only to learn that there were serious, extremely basic flaws in their design. The Cavendish Lab's leader, Sir Lawrence Bragg, nearly fired Crick, then prohibited them both him and Watson from working on DNA ever again. Crick and Watson's research was a process of trial and error with no guarantee of success—and an error would lead to serious consequences. But they kept going regardless. They struggled with the problem of DNA structure for months, without making much real progress. Then, they discovered the solution all at once, in a single morning, and ecstatically realized that they had found "the secret of life." In fact, this discovery depended on a series of coincidences—like a crucial X-ray photo from Rosalind Franklin's lab, a seemingly unrelated paper by Erwin Chagaff, and a fortuitous mistake in a biochemistry textbook. The circumstances surrounding their solution underline Watson's message about the unpredictability, high stakes, and sheer thrill of scientists' work.

Watson and Crick may fit the stereotype of eccentric intellectuals, but they became scientists and studied DNA for perfectly ordinary, relatable reasons: they wanted to go on an exciting adventure. The quest for DNA gave meaning to their lives because, fundamentally, it was really a quest for truth, status, and belonging. Therefore, even if many of Watson's readers can't understand the complicated molecular biology behind **the double helix structure**, they can empathize with the basic human motivations behind his search for it. And if they do, then *The Double Helix* will have achieved its goal: to reveal the human truth behind scientific research.

SCIENTIFIC COLLABORATION, COMPETITION, AND COMMUNITY

The Double Helix tells the story of Francis Crick and James Watson's revolutionary discovery about the structure of DNA, but the book is more about the people behind the science than the science itself. Crick and Watson's personal friendship was the foundation for their research, while their rivalries with other scientists—especially Linus Pauling—pushed them toward a solution. Meanwhile, their controversial relationships with Maurice Wilkins and Rosalind Franklin toed the line between collaboration and competition. In short, Crick and Watson's discovery was only possible because they were plugged into a network of other scientists. Thus, while literature and popular culture often depict scientists as isolated geniuses whose discoveries depend on individual brilliance alone, *The Double Helix* reveals a very different reality. Watson shows that every modern scientist's work fundamentally depends on their membership in the global scientific community of researchers, mentors, funders, collaborators, and rivals.

Watson and Crick's relationship was the key to their success, which shows how collaboration can shape and improve scientists' work. Watson recalls that as soon as he visited the Cavendish Lab, he instantly connected with Crick and knew that he wanted to stay at Cambridge. Soon, Watson and Crick's day-to-day lives started to revolve around their friendship and professional collaboration. This shows that collaboration isn't just a way for scientists to supplement their existing interests—it can also fundamentally change the direction of their work. But Crick and Watson's complementary expertise was what made their collaboration successful. For instance, Crick was better at high-level mathematics, which allowed him to easily understand Rosalind Franklin's complicated X-ray diffraction research, while Watson knew about DNA replication, which allowed him to understand **the double helix structure**'s advantages. Most importantly, Crick and Watson made their greatest advances by brainstorming together, not by theorizing individually. By working together, they became more knowledgeable, creative, and innovative than they would have been alone.

Moreover, Watson and Crick's discovery was only truly possible because of the scientific community that surrounded them, ranging from their mentors at Cambridge to their rivals in London and Pasadena. First and foremost, Crick and Watson's research depended on their training, their fellowship funding, and the Cavendish Laboratory's leaders, Max Perutz and Sir Lawrence Bragg. Without these resources, Crick and Watson wouldn't have had the time, money, or freedom to pursue their research at all. Next, Crick and Watson could only succeed because of a wider, international network of supporters and funders. For instance, Watson only found a position at the Cavendish Laboratory because his doctoral advisor Salvador Luria personally recommended him to Max Perutz's research partner John Kendrew. And when Watson's landlady kicked him out, Kendrew gave him a place to stay. Even more importantly, Crick and Watson only learned about Linus Pauling's research because of personal connections—Pauling's son Peter and Luria's colleague Max Delbrück kept them informed about Pauling's new theories and models. In fact, if they didn't have this information, Crick and Watson probably wouldn't have even tried to model DNA's structure a second time. Again, it's impossible to separate their groundbreaking advances from the scientific community that surrounded them.

Crick and Watson's discovery was also built on the foundation of other scientists' work. They only started studying DNA because of the work other biologists had published about it, and they only began modeling DNA as a helix after learning about Linus Pauling's alpha helix model for polypeptide chains in proteins. Similarly, Crick and Watson's final model would have been impossible without Erwin Chargaff's findings about the amount of adenine, thymine, guanine, and cytosine in DNA and John Donohue's pointers about the molecular structure of guanine and thymine. These are just a few of the numerous earlier scientists who influenced Crick and Watson; their role in the men's discovery shows that science is a collective, cumulative process in which every discovery fundamentally depends on all the work that preceded it. Most importantly, Crick and Watson's discovery would have been impossible without Maurice Wilkins and Rosalind Franklin's experimental research. Crick and Watson only confirmed the helical structure of DNA when they measured one of Rosalind Franklin's high-quality X-ray diffraction images. Since Linus Pauling didn't have this image, Franklin's research was arguably the main reason that Crick and Watson got to the double helix structure first. In this way, their discovery was also a personal victory for Wilkins and Franklin, as well as a collective one for the whole scientific community.

While Crick and Watson's unique insights led them to the structure of DNA, other scientists made these insights possible. Still, this doesn't necessarily mean that Watson has given these other scientists all the credit they are due. Most importantly, critics, historians, and fellow scientists have consistently argued that Watson distorts and understates Rosalind Franklin's legacy in *The Double Helix*. Crick and Watson's decision to use Franklin's data without her knowledge or consent has ignited a decades-long ethical controversy, and scientists today widely consider Watson a model of impropriety and dishonor in their profession. Thus, while Watson recognized the scientific community's importance to modern research, this does not mean that he recognized or respected scientists' ethical obligations to one another within that community.

DNA AND THE SECRET OF LIFE

James Watson wrote *The Double Helix* fifteen years after he and Francis Crick discovered the structure of DNA and six years after they shared a Nobel Prize with Maurice Wilkins. By then, scientists widely understood DNA's importance in determining individual traits and genetic inheritance (the way that parents pass traits down to their offspring). As Watson writes in *The Double Helix*, DNA is "the Rosetta Stone for unraveling the true secret of life"—it's the code that makes every organism distinct. But when Watson and Crick began their research in 1951, many chemists, biologists, and even geneticists didn't appreciate DNA's significance at all. Most thought that proteins were the key to genes, not DNA. Watson and Crick's unusual confidence in DNA's importance made their eventual success possible. While they were discovering DNA's **double helix structure**, their more experienced colleagues were busy studying much less significant topics. In fact, not only did Crick and Watson's intuitions about DNA turn out to be right, but the structure of DNA also proved their intuitions: the double helix was specifically suited to perform key genetic functions, like replication and encoding information. Thus, Watson and Crick's didn't just accurately model DNA—they also proved that DNA did exactly what they hoped that it would. In other words, Crick and Watson's discovery was significant not only because they showed the scientific establishment the structure of a new molecule, but also because they showed why the molecule's structure revealed its function as the "secret of life."

The first important step in Watson and Crick's research was their interest in DNA: they understood its central significance for genetics before almost anyone else. Watson explains that this began with their interest in O.T. Avery's experiments on bacteria in the 1940s. Avery showed that DNA molecules could transfer hereditary traits between different bacteria, which suggested that these traits—and the genes that underly them—are located in DNA. However, most biologists and geneticists overlooked or discounted Avery's studies at first. Instead, they continued to think that proteins were responsible for genes, so they tried to understand heredity by studying proteins. For instance, at an important London conference, Watson presented Al Hershey and Martha Chase's work showing that phages (bacterial viruses) use DNA to infect bacteria and reproduce themselves. This strongly supported the results of Avery's study. But, with the exception of three French virologists, most of the people at the conference didn't care about the result. This illustrates how, when Crick and Watson entered biology, most of the scientific establishment was looking for genes in the wrong place. But as young newcomers to the field, Crick and Watson could easily see the evidence in favor of DNA. Of course, they weren't the only people studying DNA. For instance, Herman Kalckar was studying its biochemistry in Copenhagen—but Watson didn't consider his research interesting or applicable enough. Similarly, Maurice Wilkins and Rosalind Franklin were studying DNA in London, but Watson emphasizes several problems with their research. For instance, they didn't get along and they didn't treat DNA with the urgency it deserved. Worse still, they insisted on understanding it using experimental X-ray diffraction studies alone—not the **molecular models** pioneered by Linus Pauling. Thus, when Watson and Crick began their research, they clearly saw that most researchers were ignoring DNA, and most DNA researchers were ignoring the methodology most likely to uncover the truth about it.

When Crick and Watson discovered DNA's double helix structure, they also provided very strong evidence for their hypothesis that DNA carries genes and is responsible for genetic inheritance. First, Crick and Watson proved that DNA can have a regular, consistent shape despite having a long, irregular sequence of nitrogenous bases. This supported Crick and Watson's hypothesis that different people's DNA could have a different sequence of bases but the same overall molecular form. Second, Crick and Watson established that DNA could replicate itself. They proved this by showing that DNA's two strands are complimentary mirror images: adenine always bonds with thymine, and guanine always bonds with cytosine. For example, if one strand has adenine, then guanine, then cytosine, the other strand will have thymine, then cytosine, then guanine. This means that either of the two strands can serve as a template for creating a totally new strand of DNA. Thus, if the strands separate, the organism to which they belong can create new DNA molecule. By repeating this process, it can replicate its own DNA millions of times. (Several years after discovering the double helix structure, Crick and Watson discovered that this process happens through mRNA, a molecule similar to DNA.) This feature strongly supported Crick and Watson's hypothesis that DNA was the "secret to life" because it explained how a person could develop from a small collection of fertilized cells to a complex organism with the same DNA in every cell.

In *The Double Helix*, Watson doesn't explain how the discovery of DNA's structure has revolutionized biology and genetics—his readers are likely to already know. Instead, he points out how things could have been otherwise: DNA could have simply been just another molecule, with no special function or structure. There would have been no Nobel Prize and no revolution. Thus, Watson emphasizes that his and Crick's discovery wasn't merely revolutionary because it revealed the molecule that was eventually proven to be the key to life. Instead, they revealed the molecule *and* showed why it was the key to life all at once.

ACADEMIC LIFE AND THE UNIVERSITY

The Double Helix isn't just the tale of a landmark scientific discovery—it's also a coming-of-age story. At just 22 years old, James Watson left his home in the U.S. to do biology research on a fellowship in Copenhagen. Little did he know that he'd end up spending most of a decade working at the University of Cambridge in England—and become a world-famous scientist in the process. Thus, the years that Watson chronicles in this book were also important years of personal growth for him. If his PhD taught him what it meant to do serious scholarly work, then his years at Cambridge taught him what it meant to live a serious scholarly life. In *The Double Helix*, Watson celebrates the privileges that this scholarly life gave him, particularly in the unique, cloistered environment of Cambridge. The most significant of these privileges is academic freedom. But several other material privileges made genuine academic freedom possible for people like Watson (white men working in American and European universities in the 1950s). Throughout his book, Watson celebrates the privileges he received—which included generous fellowships, elite connections, and the opportunity to travel widely. But he also celebrates rigid gender roles that made it extremely difficult for women to pursue a scholarly career and gave men power over them in every sphere of life. Twenty-first-century readers may notice that many aspects of university life have changed since Watson's time at Cambridge—some for better and some for worse. Still, in *The Double Helix*, Watson shows how universities make scholarly life and work possible by creating the day-to-day infrastructure and environment necessary to meet academics' needs.

When Watson left the U.S. and began his scientific career, he started to understand both the great value of academic freedom and the way that freedom is conditional on institutional support. Watson began in Copenhagen, where he received a $3,000-a-year fellowship to study biochemistry at Herman Kalckar's lab. But he soon realized that he only needed $1,000 a year to live in Copenhagen, and at first, the Fellowship Board didn't know if he was studying with Kalckar at all. Instead, he went to study bacteriophages with Ole Maaløe, and then he moved to Cambridge to study DNA. In the process, he recognized the value of academic freedom, which let him control his time and work. However, Watson then experienced an about-face: when he finally informed the Fellowship Board that he had left Kalckar's lab, he temporarily lost his funding. Through this experience, he learned that academic freedom is as conditional as it is valuable. Therefore, he set about looking for a middle ground: to receive funding, he needed to prove that his research was appropriate for him and useful to the world, but he also wanted the luxury to experiment with new ideas. This is how he ended up earning funding at Cambridge, where he was technically supposed to study plant viruses but actually spent much of his time learning about DNA. Thus, Watson's experience showed him that academic freedom is only possible within certain limits—which institutions like universities and the fellowship board were responsible for setting.

Watson soon decided that the University of Cambridge was an ideal site for an academic life—pleasant, comfortable, and intellectually stimulating, it allowed scholars to take full advantage of their academic freedom. The first thing that Watson noticed about Cambridge was its architecture. He writes that "I had never seen such beautiful buildings in all my life, and any hesitation I might have had about leaving my safe life as a biologist vanished." For Watson, then, Cambridge's cloistered beauty represented the comfort and serenity of a scholarly life. But Cambridge also gave Watson everything he needed to survive and free his time for intellectual pursuits. He spends much of the book discussing the different places he stayed and his search for a good meal. While he wished for better heating and tastier food, he always managed to rent a room and never had to cook, and he points out that these luxuries allowed him to dedicate all of his energy to science. Finally, Watson sees Cambridge's social scene as its most important advantage. He was surrounded by brilliant, renowned researchers, and famous biologists frequently visited the university to present their work. This stimulated his thinking and improved his research.

But Watson also emphasizes another aspect of Cambridge's social scene: the parties and the access to women. Some readers might find it disturbing that Watson constantly tried (and consistently failed) to meet undergraduate women. (So did Watson's collaborator Francis Crick, even though he was 12 years older than Watson—and already married.) In fact, Watson clearly views the restrictions put on women as a critical part of Cambridge's appeal. For instance, he appreciated that Crick's wife, Odile, cooked well but didn't know anything about science—and he hoped to find a similar wife for himself. Similarly, Watson's constant negative comments about feminism and Rosalind Franklin—whose appearance and demeanor he saw as unwomanlike—show that he simply doesn't believe that women should be equal to men in the university. Rather, he envisions a system in which male scholars do intellectual work while women their wives, secretaries, and female students cater to their needs. In other words, Watson celebrates men's academic freedom in the universities of the 1950s *because* it was conditioned on women's oppression. Thus, while Watson shows how universities can unleash scholars' potential by giving them academic freedom and meeting their material needs, he also inadvertently shows his readers how this version of the university is severely limited: it protects some people's right to academic freedom only by denying that right to others.

SYMBOLS

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

MOLECULAR MODELS

In addition to visually representing their various theories of DNA, Crick and Watson's 3-D molecular models also come to represent their unconventional methods, unpopular preference for theoretical over practical work, and heavy reliance on other scientists' research. When they learned that Linus Pauling discovered the structure of the alpha helix by putting together molecular models, Crick and Watson realized that they could do the same for DNA. This was fitting for them: Crick loved theorizing about data, but hated collecting it, while Watson was still extremely young when he met Crick and didn't know anything about experimental methods like crystallography yet.

However, Crick and Watson's decision to use molecular models went against popular wisdom in the scientific community. Most importantly, other DNA researchers—like Maurice Wilkins and (especially) Rosalind Franklin—strongly believed that only experimental methods like X-ray diffraction could bring scientists closer to understanding DNA. (In fact, it took three years of conversation with Crick and Watson before Maurice Wilkins was willing to try out molecular models.) Even Pauling generally used a combination of experiments and molecular modeling. Therefore, many scientists were astonished to see Crick and Watson discover DNA through molecular models, after conducting no experiments of their own. In fact, their theoretical approach allowed them to make a world-changing discovery despite their youth and inexperience. However, it never could have worked if they didn't have other people's data—like phage researchers' results about virus DNA, Erwin Chargaff's work on nitrogenous bases, and most importantly, Rosalind Franklin's X-ray images of DNA.

THE DOUBLE HELIX STRUCTURE

For Watson and Crick, DNA's double helix structure wasn't just an interesting solution to a difficult puzzle or an exciting pathway to fame: it also embodied the elegance in nature that led them to become scientists in the first place.

Of course, as soon as they discovered the double helix structure, Crick and Watson knew that their lives were going to change forever. They had solved an important scientific problem, and their research had the potential to profoundly transform biology and genetics. At the very least, elder scientists could no longer dismiss them, their methods, or their work—they had clearly won acceptance in the scientific community.

But the double helix structure is truly remarkable because it explains itself: its form reveals its function. In fact, the double helix's form is so clear and its function is so efficient that, when Crick and Watson discovered it, they erased all doubt that DNA could be "the secret of life." First, the double helix structure can carry an irregular series of nitrogenous bases, which encode genetic information. Second, it allows DNA to easily replicate itself—the double helix's two strands can easily separate and serve as templates for the creation of more DNA. (Crick and Watson would later discover that this process depends on mRNA, a molecule related to DNA.) This replication process enables organisms to grow over time. It's difficult to imagine a more effective or less complex form for DNA to take.

In this sense, Crick and Watson's solution was even better than they had hoped for: it left scientists with no doubts about DNA's role or significance. In fact, the double helix was so persuasive because of its simplicity. It shows that, even if biology is endlessly complicated, nature's beauty truly lies in its elegance and efficiency.

QUOTES

Note: all page numbers for the quotes below refer to the Touchstone Books edition of *The Double Helix* published in 1968.

Preface Quotes

As I hope this book will show, science seldom proceeds in the straightforward logical manner imagined by outsiders. Instead, its steps forward (and sometimes backward) are often very human events in which personalities and cultural traditions play major roles. To this end I have attempted to re-create my first impressions of the relevant events and personalities rather than present an assessment which takes into account the many facts I have learned since the structure was found. Although the latter approach might be more objective, it would fail to convey the spirit of an adventure characterized both by youthful arrogance and by the belief that the truth, once found, would be simple as well as pretty.

Related Characters: James D. Watson (speaker), Francis Crick

Related Themes:

Page Number: xi

Explanation and Analysis

Watson introduces *The Double Helix* by laying out what he hopes to accomplish in the book. It's more than simply explaining DNA or recalling his youth—rather, he wants to give his reader a new perspective on science. Specifically, he argues that outsiders' assumptions about science are very different from how it actually works. He implies that these outsiders think of science as a series of objective truths about the world, so they mistakenly assume that scientists simply follow a predetermined process to uncover these truths, one after the other.

It's true that scientists try to generate precise, replicable results, which allows humanity to gradually accumulate new knowledge and develop new technology over time. But this doesn't mean that scientists learn something new every day, or that every experiment they perform yields meaningful results. In fact, as Watson explains here, scientists often have to go through convoluted processes of trial and error in order to generate linear, logical explanations of how the world works. In science, *people* decide what lines of research to pursue, how to pursue them, and when the results of that research are legitimate. Scientists' norms, prejudices, and expectations all shape their work—just like in any other field. Therefore, in this book, Watson emphasizes the human side—not the technical side—of his research with Crick. This is why he chooses to write from the adventurous, naïve, and frequently prejudiced perspective of his younger self.

❝ I feel the story should be told, partly because many of my scientific friends have expressed curiosity about how the double helix was found, and to them an incomplete version is better than none. But even more important, I believe, there remains general ignorance about how science is "done." That is not to say that all science is done in the manner described here. This is far from the case, for styles of scientific research vary almost as much as human personalities. On the other hand, I do not believe that the way DNA came out constitutes an odd exception to a scientific world complicated by the contradictory pulls of ambition and the sense of fair play.

Related Characters: James D. Watson (speaker), Francis Crick , Rosalind Franklin

Related Themes:

Related Symbols:

Page Number: xii

Explanation and Analysis

In his preface to *The Double Helix*, Watson emphasizes that this book is nothing more and nothing less than his own perspective on the past. In many memoirs, this goes without saying, but in Watson's, it's important to make this disclaimer because the personal and professional dynamics that he describes in the book had important consequences. After all, Watson and Crick's research was a matter of public interest.

Virtually all of Watson's former colleagues were still working when he published this book, and many of them expressed major concerns about his manuscript. Most importantly, Crick objected to the way that Watson described him, and many of Rosalind Franklin's friends and colleagues thought that Watson was extremely unfair to her, too. Therefore, this part of the preface was Watson's way of acknowledging the critiques and controversies that he faced. Just like his research, his version of events depends on his particular personality, which means that his readers shouldn't take it as objective fact.

However diverse scientists' research styles may be, Watson continues, one commonality that all scientists face is the tension between "ambition and the sense of fair play." Scientists both want to promote their own work and fulfill their professional obligations—they have strong personal incentives to act selfishly but also a strong sense of professional honor that pushes them to act selflessly. Watson is, of course, referring to his and Crick's race to discover the DNA structure before other scientists—and, even more controversially, their reliance on other scientists' unpublished data. While Watson does not expect everyone to agree with his choices or deem them ethical, he hopes that his readers can at least understand them by understanding the context in which he made them.

Chapter 1 Quotes

❝ I have never seen Francis Crick in a modest mood.

Related Characters: James D. Watson (speaker), Francis Crick

Related Themes:

Page Number: 7

Explanation and Analysis

Watson begins *The Double Helix* with this bold, controversial statement about his friend and research partner Francis Crick. In fact, the entire first chapter is a kind of homage to Crick, whose personality made a strong and immediate impression on Watson when he arrived in Cambridge. After all, Crick was far older and more experienced than Watson (even though Watson had already finished his PhD and Crick had not). And this book suggests that, over the course of their time together, Watson learned more about life and science from his friendship with Crick than he did from any other source (including his own research). Therefore, Watson's portrait of Crick is really an expression of his affection for him.

While Watson does highlight many of Crick's shortcomings—like the arrogance implied here—his point is really that the foundation for their research was their similarly eccentric personalities. If their personalities hadn't meshed, they never would have become friends. If they hadn't become friends, they never would have worked together. And of course, if they hadn't worked together, they never would have discovered the structure of DNA. In fact, Crick's utter lack of modesty was probably one of the most important ingredients in their success. After all, the structure of DNA was an extremely ambitious research topic for scientists as young as Watson and Crick were. Thus, Watson starts his book with an affectionate portrait of Crick in order to reinforce his point that science always depends on people and relationships.

Though he was generally polite and considerate of colleagues who did not realize the real meaning of their latest experiments, he would never hide this fact from them. Almost immediately he would suggest a rash of new experiments that should confirm his interpretation. Moreover, he could not refrain from subsequently telling all who would listen how his clever new idea might set science ahead.

As a result, there existed an unspoken yet real fear of Crick, especially among his contemporaries who had yet to establish their reputations. The quick manner in which he seized their facts and tried to reduce them to coherent patterns frequently made his friends' stomachs sink with the apprehension that, all too often in the near future, he would succeed, and expose to the world the fuzziness of minds hidden from direct view by the considerate, well-spoken manners of the Cambridge colleges.

Related Characters: James D. Watson (speaker), Francis Crick

Related Themes:

Page Number: 10

Explanation and Analysis

Francis Crick's brilliance, arrogance, and endless curiosity often got the best of him, which led to problems with his colleagues. As Watson portrays him, Crick was interested in practically everything in science—except doing experiments. Unlike many other scientists, Crick much preferred interpreting data to gathering it, so he tended to find the scientists who *did* gather data and start telling them what this data meant.

Crick's experience reveals several important principles about the world of science. It shows how understanding the significance of experiments is often far more important than conducting them well, how universities can actually stifle innovation by protecting the scientific establishment, and how fame motivates research. But most importantly, it also shows that there is a fine line between collaboration and theft: while Crick's ideas could very well "set science ahead" as a whole, they also threatened to undermine his colleagues, whose careers depended on their receiving credit for the fruits of their research. In fact, Crick and Watson ultimately discovered the structure of DNA by borrowing and theorizing from others' data in exactly this way. This is part of why their work raised such serious controversy.

Chapter 2 Quotes

Of course there were scientists who thought the evidence favoring DNA was inconclusive and preferred to believe that genes were protein molecules. Francis, however, did not worry about these skeptics. Many were cantankerous fools who unfailingly backed the wrong horses. One could not be a successful scientist without realizing that, in contrast to the popular conception supported by newspapers and mothers of scientists, a goodly number of scientists are not only narrow-minded and dull, but also just stupid.

Related Characters: James D. Watson (speaker), Francis Crick

Related Themes:

Page Number: 14

Explanation and Analysis

Crick and Watson's shared interest in DNA turned their budding friendship into a serious research partnership. Today, it's common knowledge that genes are specific sequences in DNA, but in the early 1950s, scientists hadn't yet discovered this. In fact, they widely disagreed, and only a minority—including Crick and Watson—were convinced by the evidence for DNA.

This is a crucial point for understanding the significance of Watson and Crick's work: they didn't just show how DNA was structured; at the same time, they also showed that DNA was the key genetic material, when most scientists didn't believe it.

After noting that he and Crick were in the minority, Watson also takes the opportunity to harshly criticize other scientists. Readers may or may not agree with his characterization, but Watson's real purpose is to again emphasize how the reality of science is nothing like the popular stereotypes. There are many different kinds of scientists who do many different kinds of work for many different kinds of reasons. Some are rigidly conventional, some might not understand the true implications of what they study, and according to Watson, some are simply stupid. This has significant implications for scientific progress, because it suggests that often only a small vanguard can really understand the truth or know where future discoveries and innovations are likely to come.

The real problem, then, was Rosy. The thought could not be avoided that the best home for a feminist was in another person's lab.

Related Characters: James D. Watson (speaker), Rosalind Franklin , Maurice Wilkins

Related Themes:

Page Number: 20

Explanation and Analysis

After explaining that Maurice Wilkins was England's preeminent DNA researcher in 1951, Watson introduces the greatest issue with Wilkins's work: his research partner, Rosalind Franklin (whom Watson refers to as Rosy). According to Watson, Franklin was impossible for Wilkins to work with because she wouldn't dress like a respectable woman, refused to follow Wilkins's orders, and (worst of all) talked about women's equality. Not only was she a woman in what Watson considered a man's role, but she was actively trying to make science more inclusive. Therefore, Watson concluded that Wilkins should have kicked Franklin out of his lab.

Watson's comments can be read as misogynistic. Like many of his colleagues, he openly believed that women did not belong in science—or, at least, not in significant numbers or positions of authority. Watson constantly emphasizes the importance of personal relationships and collaboration in science, so regardless of their feelings about DNA, his readers must grapple with the relationship between his science and his sexism. It's important to remember that, although Watson first met Franklin in England in 1951, he published this book in a much more socially progressive time and place: the U.S. in 1968. In fact, many decades later, his views still remained largely the same. For instance, later in life, he continued to argue that men are genetically predisposed to be better scientists than women.

Watson's attitudes toward Franklin had important scientific and professional consequences: they influenced his unwillingness to give her credit for her work and his eventual decision to take her data without her authorization. They also shaped her (and other women's) access to the universities, research funding, and social networks that make successful science possible. Therefore, it's impossible to simply dismiss Watson's sexism as irrelevant to biology.

But Watson's comments about Franklin are also puzzling for another reason. Rosalind Franklin *wasn't* Wilkins's assistant, and she *didn't* go by the nickname "Rosy." Many other details from Watson's account were also demonstrably false—for instance, Rosalind Franklin didn't wear glasses. Although impossible to say where the truth ends and Watson's distortions begin, readers also have to grapple with the question of why Watson would make these claims. Tragically, Franklin was the only person mentioned in Watson's book who died before its publication, so couldn't respond to it. Thus, it's no surprise that Watson's comments about Franklin are responsible for the most significant and long-lasting of the controversies surrounding this book.

Chapter 3 Quotes

Knowing he could never bring himself to learn chemistry, Luria felt the wisest course was to send me, his first serious student, to a chemist.

He had no difficulty deciding between a protein chemist and a nucleic-acid chemist. Though only about one half the mass of a bacterial virus was DNA (the other half being protein), Avery's experiment made it smell like the essential genetic material. So working out DNA's chemical structure might be the essential step in learning how genes duplicated. Nonetheless, in contrast to the proteins, the solid chemical facts known about DNA were meager. Only a few chemists worked with it and, except for the fact that nucleic acids were very large molecules built up from smaller building blocks, the nucleotides, there was almost nothing chemical that the geneticist could grasp at.

Related Characters: James D. Watson (speaker), Salvador Luria , Francis Crick

Related Themes:

Page Number: 23-24

Explanation and Analysis

Watson earned his PhD at Indiana University, where his advisor was the microbiologist and bacteriophage (bacterial virus) researcher Salvador Luria. The bacteriophage researchers viewed bacteriophages as a useful way to understand genes more broadly, because they were simple and easy to study. And Oswald Avery's early bacteriophage experiments strongly suggested that DNA, then a relatively understudied molecule, was the key to how bacteriophages replicated after infecting bacteria. In fact, Avery's experiments were the genesis of Watson's career: they explain why Watson was one of the first researchers to focus his career on DNA.

Watson and Luria's interest in DNA explains why Watson ended up in Europe after finishing his PhD—and, eventually, why he ended up working with Crick at Cambridge. After Avery's experiments, biologists needed to learn more about DNA—both to confirm whether it was truly the source of genes and to show how it enabled organisms to develop. This is the backdrop against which Crick and Watson conducted their research, and it explains why their work was so significant. They fundamentally reoriented the scientific community's thinking about genes and heredity.

Chapter 5 Quotes

❝❞ I proceeded to forget Maurice, but not his DNA photograph. A potential key to the secret of life was impossible to push out of my mind. The fact that I was unable to interpret it did not bother me. It was certainly better to imagine myself becoming famous than maturing into a stifled academic who had never risked a thought.

Related Characters: James D. Watson (speaker), Maurice Wilkins , Herman Kalckar

Related Themes:

Page Number: 35

Explanation and Analysis

After finishing his PhD, Watson went to Copenhagen to research the chemistry of DNA. But he soon realized that his supervisor, Herman Kalckar, didn't connect this chemistry work to genetics. Therefore, he started looking for another line of research. He found it at a conference in Naples, where he learned about Maurice Wilkins's X-ray diffraction studies on DNA. This discovery persuaded him to drop everything and move to Cambridge to do similar work.

Watson's response to Wilkins's X-ray images shows what truly motivated him to pursue DNA research (and a scientific career more generally). DNA fascinated Watson because it appeared to be "the secret of life"—or the key to understanding how organisms develop, reproduce, and pass on their unique traits. Watson was chasing this mystery, and science gave him the tools to decode it. But he was also thinking about fame and adventure. He wanted anything but the stereotypical quiet scientific life, full of research so specialized that it wouldn't affect ordinary people. Instead, he deliberately chose a risky and cutting-edge research topic that was far more likely to cause a paradigm shift in biology.

❝❞ From the moment the several hundred delegates arrived, a profusion of free champagne, partly provided by American dollars, was available to loosen international barriers. Each night for a week there were receptions, dinners, and midnight trips to waterfront bars. It was my first experience with the high life, associated in my mind with decaying European aristocracy. An important truth was slowly entering my head: a scientist's life might be interesting socially as well as intellectually. I went off to England in excellent spirits.

Related Characters: James D. Watson (speaker)

Related Themes:

Page Number: 40

Explanation and Analysis

Shortly after finding a sense of professional direction at a conference in Naples, Watson found a sense of personal direction at a conference back in Copenhagen—which was really more of an all-expenses-paid party for him and his colleagues. This conference was like an initiation rite: it showed Watson a crucial side of academic life that he hadn't yet come to appreciate. Thanks largely to the Cold War, there was plenty of U.S. government money to go around in the scientific community. And Watson quickly realized that this community was really a social network as well as a professional one. There didn't need to be a clear separation between professional and private life, or even between the office, home, and "waterfront bars": academic life gave people like Watson the opportunity to fully immerse themselves in the problems that most interested them and a network of people who shared that interest. Thus, in addition to humanizing science and the people who do it, Watson's insight also reinforces his case for why academic life is such a valuable gift.

Chapter 6 Quotes

Max Perutz was in his office when I showed up just after lunch. [...] I explained that I was ignorant of how X-rays diffract, but Max immediately put me at ease. I was assured that no high-powered mathematics would be required: both he and John had studied chemistry as undergraduates. All I need do was read a crystallographic text; this would enable me to understand enough theory to begin to take X-ray photographs.

[...]

When Max realized that I had come directly to the lab from the station and had not yet seen any of the colleges, he altered our course to take me through King's, along the backs, and through to the Great Court of Trinity. I had never seen such beautiful buildings in all my life, and any hesitation I might have had about leaving my safe life as a biologist vanished.

Related Characters: James D. Watson (speaker), Max Perutz , John Kendrew , Francis Crick

Related Themes:

Page Number: 41-42

Explanation and Analysis

Watson admits that he knew nothing about crystallography or Cambridge when he arrived in Cambridge to become a crystallographer. Fortunately, his new supervisor, Max Perutz, was more than willing to introduce him to both. Thus, his time at Cambridge started off on the right foot: he immediately confirmed that he was in the right place to do the research he envisioned and surrounded by people who would help him reach his potential.

Watson's arrival in Cambridge reveals quite a lot about the circumstances that enabled his work to succeed. First, Watson is open about how utterly inexperienced he was when he began studying DNA. This made his and Crick's discovery all the more remarkable, since the other scientists doing similar work had decades of experience. Second, Watson again shows how relationships and the trust they fostered were the key to his work's success. And finally, Watson explains how he began to see Cambridge as the ideal site for an academic life. He emphasizes his sense of comfort and safety there, and he suggests that the university's sheer beauty made it the perfect place for scholars and researchers to investigate the fundamental mysteries of the universe. In part, this is because it was separated off from the rest of the world; at Cambridge, the complications of everyday life didn't exist, and Watson and his colleagues could dedicate all of their mental energy to their research.

Chapter 7 Quotes

From my first day in the lab I knew I would not leave Cambridge for a long time. Departing would be idiocy, for I had immediately discovered the fun of talking to Francis Crick. Finding someone in Max's lab who knew that DNA was more important than proteins was real luck. Moreover, it was a great relief for me not to spend full time learning X-ray analysis of proteins. Our lunch conversations quickly centered on how genes were put together. Within a few days after my arrival, we knew what to do: imitate Linus Pauling and beat him at his own game.

Related Characters: James D. Watson (speaker), Max Perutz , Francis Crick , Linus Pauling

Related Themes:

Page Number: 48

Explanation and Analysis

After the beautiful buildings, the second thing that captivated Watson at Cambridge was Francis Crick. Their connection was almost instant. Not only did they enjoy one another's company, but they also shared a commitment to understanding more about DNA (even while everyone else in their lab was studying proteins). In fact, they also quickly settled on a shared approach to DNA: they knew that in order to understand its function in genetics, they had to discover its underlying structure. And they agreed that experimental evidence could only be useful up to a point.

Thus, within just a few days of his arrival at Cambridge, Watson had developed the key connection and research project that would occupy him for most of the next two years. Needless to say, Watson and Crick's relationship went on to influence Watson's life and work at Cambridge far more than any other factor.

In place of pencil and paper, the main working tools were a set of molecular models superficially resembling the toys of preschool children.

We could thus see no reason why we should not solve DNA in the same way. All we had to do was to construct a set of molecular models and begin to play—with luck, the structure would be a helix.

Related Characters: James D. Watson (speaker), Linus Pauling , Francis Crick , Maurice Wilkins , Rosalind Franklin

Related Themes:

Related Symbols:

Page Number: 50-51

Explanation and Analysis

After Watson arrived at Cambridge, Crick explained Linus Pauling's alpha helix research to him. Pauling discovered the alpha helix's structure not through intensive experiments, but by using existing data and basic chemistry principles to build a theoretical model of the molecule. As Watson explains in this passage, this method was clearly applicable to his and Crick's DNA research, too. Nevertheless, this also proved very controversial, because molecular models put theory above experimental data. Crick and Watson quickly learned that Maurice Wilkins and Rosalind Franklin, England's other main DNA researchers, refused to touch molecular models. But Crick and Watson figured that if Pauling, the world's most famous chemist, was using these models, then certainly they were a legitimate scientific tool.

Crick and Watson's decision to use molecular models shows how their willingness to innovate, fail, and improve on other scientists' ideas was key to their success. In this way, their youth and relative inexperience became an asset, not a liability: it enabled them to approach problems from a new, more creative angle.

Chapter 11 Quotes

The wrong person had been sent to hear Rosy. If Francis had gone along, no such ambiguity would have existed. It was the penalty for being oversensitive to the situation. For, admittedly, the sight of Francis mulling over the consequences of Rosy's information when it was hardly out of her mouth would have upset Maurice. In one sense it would be grossly unfair for them to learn the facts at the same time. Certainly Maurice should have the first chance to come to grips with the problem. On the other hand, there seemed no indication that he thought the answer would come from playing with molecular models. Our conversation on the previous night had hardly alluded to that approach. Of course, the possibility existed that he was keeping something back. But that was very unlikely—Maurice just wasn't that type.

Related Characters: James D. Watson (speaker), Francis Crick , Rosalind Franklin , Maurice Wilkins

Related Themes:

Related Symbols:

Page Number: 76

Explanation and Analysis

Watson attended one of Rosalind Franklin's talks in order to learn more about her DNA crystallography results and the X-ray diffraction technique that they relied on. Characteristically, his first thoughts focused on her appearance—but eventually, he got around to focusing on her presentation. Later, on their train to Oxford, Watson explained Franklin's results to Crick. In the process, he realized that he didn't truly understand them and he started to wonder what would have happened if Crick had gone to Franklin's presentation instead.

Watson knew that Crick certainly would have understood Franklin better, but he also likely would have caused problems: if Crick let it be known that he was also researching DNA's structure, then Maurice Wilkins might have felt offended, because that was *his* field. Moreover, Watson believed that he and Crick had less of a right to use Franklin's data than Wilkins did—his rationale for this was that Franklin was Wilkins's assistant. (Though this isn't historically accurate—Franklin and Wilkins were actually research partners.) At the same time, Watson also wondered if Wilkins and Franklin would make real progress on DNA, because they were only doing experiments and not using molecular models.

When Watson runs through all of these principles and hypotheticals, he is really trying to make a decision between two competing scientific values: knowledge and community. On the one hand, he values his and Crick's research, which certainly would have benefited if Crick had gone to the presentation. On the other, he knows that it's important to respect other scientists' work—which would have meant giving Wilkins the first shot at modeling DNA. In turn, Watson's conflict of values depends on a more fundamental tension between scientists (as individuals) and science (as a collective project). While it's better for science as a whole if multiple researchers address the same problem from different angles, this creates practical challenges, because scientists also need to have their individual achievements recognized. Thus, Watson was calculating whether the personal and scientific benefits of studying DNA outweighed the personal harm that doing so would inflict on Maurice Wilkins and Rosalind Franklin.

Chapter 13 Quotes

Most annoyingly, her objections were not mere perversity: at this stage the embarrassing fact came out that my recollection of the water content of Rosy's DNA samples could not be right. The awkward truth became apparent that the correct DNA model must contain at least ten times more water than was found in our model. This did not mean that we were necessarily wrong—with luck the extra water might be fudged into vacant regions on the periphery of our helix. On the other hand, there was no escaping the conclusion that our argument was soft. As soon as the possibility arose that much more water was involved, the number of potential DNA models alarmingly increased.

Related Characters: James D. Watson (speaker), Rosalind Franklin , Francis Crick , Maurice Wilkins

Related Themes:

Page Number: 94

Explanation and Analysis

After Crick and Watson developed their first model of DNA, they eagerly invited Maurice Wilkins and Rosalind Franklin to visit Cambridge and see it. Unfortunately, Crick and Watson soon learned that they were far off the mark—Franklin pointed out several serious problems with their model. Most egregiously, she noted that Watson seemed to have misremembered the data from her talk. Crick and Watson felt defeated and humiliated; their model no longer seemed plausible.

Watson clearly intended to use this episode to convey other lessons, ranging from the value of modesty to the importance of taking notes during other people's presentations. Clearly, in their eagerness and hope to find DNA's structure, Watson and Crick lost sight of the reality of the problem—which was far more complex than they had imagined.

Meanwhile, contemporary readers might empathize more with Franklin than Watson and consider the gender dynamics of this passage. Watson gets angry at Franklin and talks down to her because she corrected his serious misunderstanding of her own research. Worse still, Franklin had been performing her experiments for years, while Crick and Watson threw their model together in just a couple days. The way Watson treats Franklin (considered alongside his sexist comments about her in previous chapters) implies that he doesn't take her seriously because she's a woman, even though she has more expertise in the field than Watson and Crick do.

Chapter 14 Quotes

Sir Lawrence had had too much of Francis to be surprised that he had again stirred up an unnecessary tempest. There was no telling where he would let loose the next explosion. If he continued to behave this way, he could easily spend the next five years in the lab without collecting sufficient data to warrant an honest Ph.D. The chilling prospect of enduring Francis throughout the remaining years of his tenure as the Cavendish Professor was too much to ask of Bragg or anyone with a normal set of nerves.

[...]

The decision was thus passed on to Max that Francis and I must give up DNA. Bragg felt no qualms that this might impede science, since inquiries to Max and John had revealed nothing original in our approach.

Related Characters: James D. Watson (speaker), Francis Crick , Sir Lawrence Bragg , John Kendrew , Max Perutz , Rosalind Franklin , Maurice Wilkins

Related Themes:

Page Number: 97-98

Explanation and Analysis

When Crick and Watson proposed a half-baked DNA model to Maurice Wilkins and Rosalind Franklin, they didn't just embarrass themselves—their carelessness also reflected poorly on the Cavendish Lab as a whole. Crick and Watson's boss, the world-famous physicist Sir Lawrence Bragg, angrily banned them from working on DNA and ordered them to get back to their ordinary work.

Crick and Watson's blunder became a cautionary tale—it brought many of their errors into sharp focus. For one, while scientists can refine their theories through trial and error, it's important for them to find and correct those errors by themselves. Similarly, scientists can protect their reputations by erring on the side of caution, and they shouldn't stray too far from their areas of expertise. Thus, even though Crick's broad curiosity and sharp intellect made him a better scientist, these qualities were also starting to become serious liabilities. They were leading him into dangerous territory—topics he knew little about—and distracting him from his PhD research. But most importantly, scientists have to think about their professional decisions' effects on the people around them. When Watson and Crick invited Wilkins and Franklin to visit, they clearly weren't thinking about how they would affect their bosses if they failed.

Thus, when Bragg sends Crick and Watson back to their ordinary research, he's emphasizing the danger in naivety, arrogance, and ambition—which often lead scientists to make poor decisions. Crick and Watson will have to show how it's possible to be both innovative and rigorous—or how young scientists can have fresh ideas without letting pride or carelessness take them over.

Chapter 16 Quotes

❝❝ My first X-ray pictures revealed, not unexpectedly, much less detail than was found in the published pictures. Over a month was required before I could get even halfway presentable pictures. They were still a long way, though, from being good enough to spot a helix.

Related Characters: James D. Watson (speaker), Francis Crick

Related Themes:

Page Number: 115

Explanation and Analysis

After Watson and Crick temporarily gave up DNA research, Watson began studying the common plant virus TMV. He hoped to prove that TMV is a helix through X-ray diffraction images. (This technique could be later applied to DNA.) This gave Watson the opportunity to master the skill that he went to England to learn. But, as he explains here, X-ray diffraction is also really hard: it takes months to do well and years to master.

This speaks to the fundamental difference between experimental and theoretical science: at least in biology, experiments generally take much more time, commitment, and expertise than theory. Of course, Crick and Watson were attracted to theory precisely because it promised faster, more decisive discoveries and allowed them to rely on other researchers' data rather than collecting their own. But after their first theory of DNA failed, Crick and Watson recognized that they had no choice but to at least try out the longer, more conventional path of research.

Chapter 18 Quotes

❝❝ The moment was thus appropriate to think seriously about some curious regularities in DNA chemistry first observed at Columbia by the Austrian-born biochemist Erwin Chargaff. Since the war, Chargaff and his students had been painstakingly analyzing various DNA samples for the relative proportions of their purine and pyrimidine bases. In all their DNA preparations the number of adenine (A) molecules was very similar to the number of thymine (T) molecules, while the number of guanine (G) molecules was very close to the number of cytosine (C) molecules. Moreover, the proportion of adenine and thymine groups varied with their biological origin. The DNA of some organisms had an excess of A and T, while in other forms of life there was an excess of G and C.

Related Characters: James D. Watson (speaker), Erwin Chargaff , Francis Crick

Related Themes:

Page Number: 125-126

Explanation and Analysis

After Watson discovered the shape of TMV, he needed a new research project, and he was itching to get back to DNA. He decided to look at new research about DNA biochemistry. Erwin Chargaff had shown that all DNA had about the same amount of adenosine as thymine and the same amount of guanine as cytosine. This was an important finding because it suggested that DNA's structure must somehow pair adenine with thymine and guanine with cytosine. Moreover, researchers who suspected DNA played a role in genetics—including Watson and Crick—generally thought that these four nitrogenous bases were DNA's way of encoding genetic information.

Therefore, Chargaff's results also appeared to show how this information was encoded. Crick and his friend John Griffith went on to show that adenosine and thymine could bond, as could guanine and cytosine. This was ultimately the foundation for Watson's realization that the two strands of DNA always form complementary pairs (adenosine/thymine or guanine/cytosine). Contemporary readers may remember this principle from their biology classes.

Chargaff's discovery shows how other scientists, besides Crick and Watson, were also constantly making advances in the study of DNA. While these other scientists gave Crick and Watson more data to use in their models of DNA structure, they also threatened to uncover the truth about DNA first. Thus, they reflect both the collaborative and competitive sides of science.

At High Table John kept the conversation away from serious matters, letting loose only the possibility that Francis and I were going to solve the DNA structure by model building. Chargaff, as one of the world's experts on DNA, was at first not amused by dark horses trying to win the race. Only when John reassured him by mentioning that I was not a typical American did he realize that he was about to listen to a nut. Seeing me quickly reinforced his intuition. Immediately he derided my hair and accent, for since I came from Chicago I had no right to act otherwise. Blandly telling him that I kept my hair long to avoid confusion with American Air Force personnel proved my mental instability.

Related Characters: James D. Watson (speaker), John Kendrew , Francis Crick , Erwin Chargaff

Related Themes:

Related Symbols:

Page Number: 130

Explanation and Analysis

After reading Erwin Chargaff's fascinating results about the amount of adenine, thymine, guanine, and cytosine in DNA, Crick and Watson had the special opportunity to meet Chargaff over dinner and discuss their research. Clearly, this access to famous scientists was one of the luxuries that came with studying at Cambridge. However, Chargaff's response was far from what they hoped: he treated them like lunatics and totally discounted their research. While Chargaff had spent years studying DNA, Crick and Watson, who were young and inexperienced, thought they could solve its mysteries in just a few months (and in their time off). In particular, Watson didn't look and talk like an ordinary scientist *or* an ordinary Chicagoan, so Chargaff assumed that his ideas about DNA were delusional.

Chargaff's reaction to meeting Crick and Watson underlines how difficult it was for them to get other scientists to take them seriously, but it also shows how out of their depth they really were when it came to DNA research. Scientists use many different factors to evaluate one another's work, and Chargaff interpreted Crick and Watson's overconfidence and eccentricity as clear signs that they weren't serious researchers. At the same time, Chargaff's behavior also shows that scientists aren't as objective and unbiased as the reader might expect—instead, their prejudices, feelings, and instincts all contribute to their work and their attitudes about other scientists' work.

Chapter 21 Quotes

It was from his father. In addition to routine family-gossip was the long-feared news that Linus now had a structure for DNA. No details were given of what he was up to, and so each time the letter passed between Francis and me the greater was our frustration. Francis then began pacing up and down the room thinking aloud, hoping that in a great intellectual fervor he could reconstruct what Linus might have done. As long as Linus had not told us the answer, we should get equal credit if we announced it at the same time.

Related Characters: James D. Watson (speaker), Francis Crick , Linus Pauling , Peter Pauling

Related Themes:

Page Number: 156

Explanation and Analysis

When Linus Pauling's son Peter started his PhD at Cambridge, he suddenly opened a line of communication between the Cavendish Lab and Caltech. When Peter read Linus Pauling's letters, Crick and Watson could learn about their greatest rival's research. Thus, when Linus wrote Peter to explain that he had discovered the structure of DNA, Crick and Watson were disheartened. Had they not given up on DNA and turned to other subjects, they might have even found it themselves. But Pauling's letter suggested that they had lost their opportunity forever. They considered trying to solve the structure at the same time, but they soon realized that this wasn't realistic.

Crick and Watson's reaction to Pauling's letter shows how deeply competition motivated their research. While their fundamental curiosity about DNA and the structure of life did motivate them, it apparently wasn't important enough to balance out their envy of Pauling. After all, when they heard about Pauling's letter, they weren't delighted to know that they would be learning about DNA's mysteries but merely frustrated that they didn't get there first. This contrasts sharply with the way other scientists, like Pauling, responded to Crick and Watson's discovery later on.

Chapter 22 Quotes

❝ I realized that the phosphate groups in Linus' model were not ionized, but that each group contained a bound hydrogen atom and so had no net charge. Pauling's nucleic acid in a sense was not an acid at all. Moreover, the uncharged phosphate groups were not incidental features. The hydrogens were part of the hydrogen bonds that held together the three intertwined chains.

Without the hydrogen atoms, the chains would immediately fly apart and the structure vanish.

Everything I knew about nucleic-acid chemistry indicated that phosphate groups never contained bound hydrogen atoms. No one had ever questioned that DNA was a moderately strong acid. Thus, under physiological conditions, there would always be positively charged ions like sodium or magnesium lying nearby to neutralize the negatively charged phosphate groups. All our speculations about whether divalent ions held the chains together would have made no sense if there were hydrogen atoms firmly bound to the phosphates. Yet somehow Linus, unquestionably the world's most astute chemist, had come to the opposite conclusion.

Related Characters: James D. Watson (speaker), Linus Pauling , Francis Crick

Related Themes:

Page Number: 160-161

Explanation and Analysis

When Watson got a look at Linus Pauling's proposal for the structure of DNA, he immediately spotted a major problem. In their own research, one of the major difficulties that Crick and Watson encountered was how to make the different parts of the nucleotide (the sugar, phosphate group, and nitrogenous base) bond together and the different nucleotides bond together to form a chain. Pauling solved this problem by adding a hydrogen atom to each phosphate group and using these extra hydrogen atoms to hold together the three strands in his model of DNA. But Watson saw that this was clearly impossible: basic principles of chemistry prohibited binding hydrogen atoms to phosphate. Worse, with a bound hydrogen atom, DNA (deoxyribonucleic *acid*) wouldn't be an acid at all. Since Pauling was the world's foremost chemist, his proposal was baffling. Did he make a basic mistake, or was he proposing a revolution in his discipline? It turned out to be the former.

Pauling's error surprised and inspired Crick and Watson. First, it meant that they still had a chance to discover the structure of DNA. And second, if a world-famous chemist like Pauling could make such a basic mistake, then surely totally unknown researchers like them could make a major discovery.

❝ Francis was explaining to John and Max that no further time must be lost on this side of the Atlantic. When his mistake became known, Linus would not stop until he had captured the right structure. Now our immediate hope was that his chemical colleagues would be more than ever awed by his intellect and not probe the details of his model. But since the manuscript had already been dispatched to the *Proceedings of the National Academy*, by mid-March at the latest Linus' paper would be spread around the world. Then it would be only a matter of days before the error would be discovered. We had anywhere up to six weeks before Linus again was in full-time pursuit of DNA.

Related Characters: James D. Watson (speaker), Francis Crick , John Kendrew , Max Perutz , Linus Pauling

Related Themes:

Page Number: 162

Explanation and Analysis

After Linus Pauling proposed an impossible structure for DNA, Crick and Watson knew that they had a chance to beat him to the final solution—but they had to act fast. Therefore, while Watson ran around Cambridge showing Pauling's mistake to other scientists, Crick started trying to persuade their supervisors, John Kendrew and Max Perutz, to let them take up DNA again. While Crick and Watson weren't *supposed* to be studying DNA, they believed that this would be their final shot. Moreover, Pauling's model was very similar to Crick and Watson's first proposal, which suggested that Crick and Watson weren't as ignorant as they may have seemed.

Crick and Watson's response to Pauling's blunder was understandable—they were as motivated by fame and professional advancement as they were by the prospect of progress in science. However, this response was also ethically questionable—rather than informing Pauling about his error, they preferred to take advantage of it. In their situation, any scientist would face a dilemma. On the one hand, they could cooperate with their rival and help them reach a solution faster, making research more efficient overall. On the other, they could build on their rival's ideas and hope to take credit for themselves. In other words, the choice between competition and collaboration in science is really a choice between self-interest and the general good.

Chapter 23 Quotes

Interrupting her harangue, I asserted that the simplest form for any regular polymeric molecule was a helix. Knowing that she might counter with the fact that the sequence of bases was unlikely to be regular, I went on with the argument that, since DNA molecules form crystals, the nucleotide order must not affect the general structure. Rosy by then was hardly able to control her temper, and her voice rose as she told me that the stupidity of my remarks would be obvious if I would stop blubbering and look at her X-ray evidence.

[…]

Without further hesitation I implied that she was incompetent in interpreting X-ray pictures. If only she would learn some theory, she would understand how her supposed antihelical features arose from the minor distortions needed to pack regular helices into a crystalline lattice.

Related Characters: James D. Watson (speaker), Francis Crick , Rosalind Franklin , Maurice Wilkins , Linus Pauling

Related Themes:

Page Number: 165-166

Explanation and Analysis

When Watson visited London to tell Maurice Wilkins about the errors in Linus Pauling's DNA model, he ended up running into Rosalind Franklin instead—and getting into a heated argument with her. Franklin explained her own research and argued that DNA wasn't a helix. But Watson was sure that he knew better, so he interrupted Franklin to explain why she was wrong about her own result. After all, Francis Crick told Watson so, and Watson trusted Crick, a graduate student, more than Franklin, an expert crystallographer.

However, despite his rudeness, Watson's understanding of DNA turned out to be correct: it *was* a helix, and Franklin's evidence didn't disprove it. Still, Watson's comments to Franklin reveal a few key principles in his research. For instance, Watson emphasized the difference between the DNA molecule's form and the order of the bases. Just like two books can have the same shape and cover, but different content inside, different DNA molecules can have the same shape but carry a different genetic code. In addition to explaining why DNA would likely be a helix, this also explains why Watson struggled so much with the shape of DNA's nitrogenous bases: they had to appear in an irregular order without changing the shape of the whole molecule. In fact, DNA could only crystallize because of this regular structure.

The instant I saw the picture my mouth fell open and my pulse began to race. The pattern was unbelievably simpler than those obtained previously ("A" form). Moreover, the black cross of reflections which dominated the picture could arise only from a helical structure. […] The real problem was the absence of any structural hypothesis which would allow them to pack the bases regularly in the inside of the helix. Of course this presumed that Rosy had hit it right in wanting the bases in the center and the backbone outside. Though Maurice told me he was now quite convinced she was correct, I remained skeptical, for her evidence was still out of the reach of Francis and me.

Related Characters: James D. Watson (speaker), Francis Crick , Rosalind Franklin , Maurice Wilkins , Max Perutz

Related Themes:

Page Number: 167-169

Explanation and Analysis

After Watson got into an explosive argument with Rosalind Franklin, Maurice Wilkins showed him one of Franklin's X-ray diffraction images. In fact, this image ended up being the key to Crick and Watson's final model of DNA. It depicted DNA's "B" form (a different structure that it takes on when it was surrounded by water). And it clearly suggested that DNA was a helix. In addition, Franklin's image also yielded crucial measurements that helped them determine the shape and size of the molecule's sugar-phosphate backbone. Despite all their conflicts with Rosalind Franklin, then, Crick and Watson likely would never have discovered DNA's true form without her data.

Thus, it's misleading to imagine Crick and Watson's discovery as completely original and independent. They were certainly the first to model DNA's structure, but to do so, they relied on many other scientists' data (and not just Franklin's). This raises important questions about how the public should assign credit for scientific work. Most importantly, should Crick and Watson get all the credit for putting the final puzzle together, or should they share that credit with the other scientists who gave them all the pieces of that puzzle?

Moreover, Wilkins and Watson's conversation about Franklin's data is also significant because of the ethical issues it raises. Watson and Crick have faced decades of criticism for their decision to use Franklin's data without her knowledge and consent. Many scientists and historians have argued that they also failed to give her the credit she was due. Of course, Maurice Wilkins and Max Perutz also played a part in this, because they helped Crick and Watson obtain Franklin's data.

Chapter 24 Quotes

Though I kept insisting that we should keep the backbone in the center, I knew none of my reasons held water. Finally over coffee I admitted that my reluctance to place the bases inside partially arose from the suspicion that it would be possible to build an almost infinite number of models of this type. Then we would have the impossible task of deciding whether one was right. But the real stumbling block was the bases. As long as they were outside, we did not have to consider them. If they were pushed inside, the frightful problem existed of how to pack together two or more chains with irregular sequences of bases. Here Francis had to admit that he saw not the slightest ray of light.

Related Characters: James D. Watson (speaker), Francis Crick , Linus Pauling , Rosalind Franklin , Maurice Wilkins

Related Themes:

Related Symbols:

Page Number: 177-178

Explanation and Analysis

When Watson and Crick started putting together molecular models for the second time, they returned to the same key structural question as before: should the sugar-phosphate backbones be on the outside or the inside? They knew that these backbones probably provided the robust structure to each strand of DNA. Meanwhile, the nitrogenous bases attached to this backbone probably contained an organism's genetic code. Because the bases and backbone were probably attached at a perpendicular angle, the bases would likely stick out from the backbone, either toward or away from the other strands. This is why the backbones were either bonded to each other on the inside of the molecule, with the bases pointing outward, or the backbones were on the outside of the molecule, and the bases pointed inward (and were possibly responsible for the bonds between the strands).

Watson and Crick began by assuming that the backbone was on the inside and the bases pointed outward. This was the approach that they took before, during their first shot at the DNA structure, and it was also the one that Linus Pauling, Rosalind Franklin, and Maurice Wilkins seemed to favor. But Watson and Crick quickly started to realize that this might not work. As they did, Watson began to admit that his real motive for keeping the backbone on the inside was fear: it would be much harder to reach a solution if the backbones were on the outside and the bases pointed inward. Not only would there be many more possibilities, but the bases would have to somehow bond to each other.

Of course, the backbone *did* end up being on the outside. But Crick and Watson's resistance to try out this possibility speaks volumes about the psychology of science. They wanted to start with the easiest option—the backbone on the inside—because they were afraid of the harder one. As Watson admits here, then, emotions strongly influenced his approach to research. Just as fear led senior scientists to cling to the fiction that genes were made of protein, it led Crick and Watson to cling to solutions that wouldn't work, because they didn't want to admit that they might be wrong and that they might have been wasting days of work.

[Maurice Wilkins] emphasized that he wanted to put off more model building until Rosy was gone, six weeks from then. Francis seized the occasion to ask Maurice whether he would mind if we started to play about with DNA models. When Maurice's slow answer emerged as no, he wouldn't mind, my pulse rate returned to normal. For even if the answer had been yes, our model building would have gone ahead.

Related Characters: James D. Watson (speaker), Francis Crick , Rosalind Franklin , Peter Pauling , Maurice Wilkins , Erwin Chargaff

Related Themes:

Related Symbols:

Page Number: 179

Explanation and Analysis

When Maurice Wilkins visited Cambridge, Crick and Watson enthusiastically pushed him to start building DNA models. Between Erwin Chargaff's discoveries, Linus Pauling's blunder, and Rosalind Franklin's X-ray images, Crick and Watson suddenly had a flood of significant new data on DNA—and a good reason to believe that if they didn't find the solution as fast as possible, someone else would beat them to it. They also had good reasons to believe that molecular models would provide the key to DNA's structure.

However, Wilkins didn't share their sense of urgency. Rosalind Franklin was about to move to another lab, and he didn't want to start working with molecular models until she left. Perhaps it was because he had already spent so long studying DNA, or perhaps he truly couldn't stand her. Regardless, he insisted that he was going to wait. This disheartened Crick and Watson, who admired Wilkins's expertise and wanted to keep collaborating with him. But it also meant that if they found a solution, it would be theirs (and Cambridge's) alone. Fortunately, Wilkins didn't have any problem with them going ahead.

Ultimately, Crick and Watson found their solution just when Wilkins began building his models. Watson never indicates whether Wilkins came to regret his decision. But it's clear that had he not decided to wait, he may have ended up discovering the double helix first. Crick and Watson's conversation with Wilkins was therefore far more consequential than any of them realized. It also shows that Crick and Watson were sensitive to their ethical obligations to other scientists who were doing similar work and therefore had a stake in its outcome. However, they only extended this courtesy to their friend Maurice Wilkins, and not to Rosalind Franklin, who also had a long history of working on DNA.

Chapter 25 Quotes

My aim was somehow to arrange the centrally located bases in such a way that the backbones on the outside were completely regular—that is, giving the sugar-phosphate groups of each nucleotide identical three-dimensional configurations. But each time I tried to come up with a solution I ran into the obstacle that the four bases each had a quite different shape. Moreover, there were many reasons to believe that the sequences of the bases of a given polynucleotide chain were very irregular. Thus, unless some very special trick existed, randomly twisting two polynucleotide chains around one another should result in a mess. In some places the bigger bases must touch each other, while in other regions, where the smaller bases would lie opposite each other, there must exist a gap or else their backbone regions must buckle in.

Related Characters: James D. Watson (speaker), Francis Crick

Related Themes:

Page Number: 182-183

Explanation and Analysis

When Watson and Crick began working out the structure of DNA for the second time, they began looking at models with the sugar-phosphate backbone on the outside and the nitrogenous bases pointing inward. This presented a unique challenge: how could the DNA molecule maintain a consistent overall shape if its bases were organized in an irregular order? As Watson points out here, since each of the bases had a different shape, their order would either create gaps and overlaps within the molecule, or else affect the shape of the sugar-phosphate backbone.

This problem created a frustrating obstacle for Crick and Watson's research. There was no easy solution to it: the only way to proceed was through trial and error. Yet this difficulty actually ended up helping them solve the mystery of DNA's structure. Specifically, they realized that when adenine and thymine bond together, they look exactly like the pair of guanine and cytosine bonded together. Thus, the DNA backbone can take a consistent form because every bond between two nitrogenous bases always has the same shape. Before, Crick and Watson worried that they would simply end up with too many possible structures for DNA; but by figuring out how to keep the structure regular, they managed to eliminate the vast majority of these structures and reach the solution.

Despite the messy backbone, my pulse began to race. If this was DNA, I should create a bombshell by announcing its discovery. The existence of two intertwined chains with identical base sequences could not be a chance matter. Instead it would strongly suggest that one chain in each molecule had at some earlier stage served as the template for the synthesis of the other chain. Under this scheme, gene replication starts with the separation of its two identical chains.

Related Characters: James D. Watson (speaker), Francis Crick

Related Themes:

Page Number: 184-186

Explanation and Analysis

Watson and Crick realized that, if DNA's sugar-phosphate backbone is on the outside and its nitrogenous bases point inward, then they needed to figure out how those nitrogenous bases bonded together. While testing out different solutions to this problem, Watson realized that each base could bond to itself. As he explains here, he became anxious and started to hope that he had found the solution: if the two chains had the same sequence of bases, they could hold the molecule together *and* they could pull apart when necessary in order to enable gene replication.

Although Watson's hypothesis about identical chains was wrong, it was still a significant advance over his previous model. This is because it showed him two key principles: a two-strand model showed how gene replication functioned, and that there could be a relationship between the sequences in each strand of DNA, even if they were irregular.

In addition to showing how scientists often make incremental progress through trial and error, this passage also allows Watson to emphasize the remarkable thrill of scientific discovery and the surprising elegance of his solution. He highlights the emotional drama of science by describing his beating pulse and his dreams about "creat[ing] a bombshell" in the scientific community. Then, he notes that this discovery would be remarkably important because it would also clearly reveal DNA's importance to the world—its mechanism for replication would be clear, which would strongly suggest that it was the basis for the genetic code.

As the clock went past midnight I was becoming more and more pleased. There had been far too many days when Francis and I worried that the DNA structure might turn out to be superficially very dull, suggesting nothing about either its replication or its function in controlling cell biochemistry. But now, to my delight and amazement, the answer was turning out to be profoundly interesting. For over two hours I happily lay awake with pairs of adenine residues whirling in front of my closed eyes. Only for brief moments did the fear shoot through me that an idea this good could be wrong.

Related Characters: James D. Watson (speaker), Francis Crick

Related Themes:

Page Number: 188

Explanation and Analysis

After realizing that the two strands of DNA might have identical sequences of nitrogenous bases, Watson lay in bed for hours, astounded. While his idea ended up being incorrect, it was much closer to the truth than any previous proposal. And more importantly, it signaled that he was on the right track—and that his dreams of scientific greatness were actually achievable.

This was the first time Watson genuinely believed that he was going to discover DNA's structure and prove that it was the central molecule in genetics. Thus, his overwhelming feelings reveal the motivations behind his scientific ambitions. He felt a mix of wonder and pride. The beautifully elegant structure he discovered astonished him because its showed that evolution manages to build structures that are far more effective, yet far simpler than ones that humans can engineer. At the same time, he knew what his discovery would mean for his career—he was only 25 years old and virtually unknown. He rightly predicted that his momentous discovery would launch him to the international fame that he had long dreamed about.

Chapter 26 Quotes

Suddenly I became aware that an adenine-thymine pair held together by two hydrogen bonds was identical in shape to a guanine-cytosine pair held together by at least two hydrogen bonds. All the hydrogen bonds seemed to form naturally; no fudging was required to make the two types of base pairs identical in shape.

[...]

The hydrogen-bonding requirement meant that adenine would always pair with thymine, while guanine could pair only with cytosine. Chargaff's rules then suddenly stood out as a consequence of a double-helical structure for DNA. Even more exciting, this type of double helix suggested a replication scheme much more satisfactory than my briefly considered like-with-like pairing.

Related Characters: James D. Watson (speaker), Erwin Chargaff , Francis Crick

Related Themes:

Related Symbols:

Page Number: 194-196

Explanation and Analysis

The day after confirming that the two strands of DNA cannot possibly have the same sequence of bases, Watson returned to the drawing board to look for a way to fit different nitrogenous bases together. He quickly realized that just as adenine, thymine, guanine, and cytosine can bond to themselves, they can also bond to each other—and, as he explains here, the adenine-thymine pair had exactly the same structure as the guanine-cytosine pair. Therefore, a pair of nucleotides held together by a hydrogen bond between adenine and thymine looks exactly like one held together by a bond between guanine and cytosine. In short, this means that if each base always bonds with its opposite, then the two strands of DNA can have complementary sequences of bases—and always assume the same form.

This insight was the key to the DNA double helix structure. (Contemporary readers may be familiar with the adenine-thymine and guanine-cytosine pairs from biology class.) This structure solved all of Crick and Watson's requirements: it explained Erwin Chargaff's observation about the quantity of the four bases, it maintained the helix structure's consistent shape, it showed how the DNA molecule held together, and it explained how DNA could replicate and enable organisms to grow.

It's significant that a theoretical insight—and not an experimental one—was the key to Crick and Watson's puzzle. Specifically, it shows that Crick and Watson were right all along to think that they were capable of cracking the DNA code, despite their youth and experience, and use molecular models in their attempts to do so.

> However, we both knew that we would not be home until a complete model was built in which all the stereo-chemical contacts were satisfactory. There was also the obvious fact that the implications of its existence were far too important to risk crying wolf. Thus I felt slightly queasy when at lunch Francis winged into the Eagle to tell everyone within hearing distance that we had found the secret of life.

Related Characters: James D. Watson (speaker), Francis Crick , Maurice Wilkins , Rosalind Franklin , Sir Lawrence Bragg

Related Themes:

Related Symbols:

Page Number: 197

Explanation and Analysis

After Watson and Crick completed their double helix model, they went to lunch—and Crick immediately started boasting about their discovery. As Watson explains here, this made him quite uncomfortable, as he hoped to at least double-check their work before telling people outside their lab about it. He learned this lesson from his and Crick's first attempt to model DNA—when they tried to present their results to Maurice Wilkins and Rosalind Franklin too soon, they publicly embarrassed themselves, then infuriated Sir Lawrence Bragg. But this time, Crick let his pride get the better of him, and he started announcing the discovery anyway.

Although comical in retrospect, this episode reveals the tension between two key scientific principles: recognition and collaboration, or arrogance and carefulness. Whereas scientists want credit for their work, some—like Crick—can overindulge this desire and actually undermine their own work as a result. On the other hand, others—like Maurice Wilkins—don't advocate for their own work at all. At various times throughout the book, Watson suggests that Wilkins's attitude actually does himself and his work a disservice because it prevents others from seeing how important DNA actually is. Watson looks for a healthy balance between these extremes, both in his response to the discovery and in this book. But readers will have to decide for themselves whether he achieves it.

Chapter 28 Quotes

> Rosy's instant acceptance of our model at first amazed me. I had feared that her sharp, stubborn mind, caught in her self-made antihelical trap, might dig up irrelevant results that would foster uncertainty about the correctness of the double helix. Nonetheless, like almost everyone else, she saw the appeal of the base pairs and accepted the fact that the structure was too pretty not to be true. Moreover, even before she learned of our proposal, the X-ray evidence had been forcing her more than she cared to admit toward a helical structure. The positioning of the backbone on the outside of the molecule was demanded by her evidence and, given the necessity to hydrogen-bond the bases together, the uniqueness of the A-T and G-C pairs was a fact she saw no reason to argue about.

Related Characters: James D. Watson (speaker), Rosalind Franklin , Francis Crick , Maurice Wilkins

Related Themes:

Related Symbols:

Page Number: 210

Explanation and Analysis

When Crick and Watson informed Maurice Wilkins and Rosalind Franklin about their double helix model, they expected some backlash—especially from Franklin. After all, "Rosy" (Franklin) had consistently argued that DNA was *not* helical, and she strongly opposed the use of molecular models to solve biology problems. Therefore, Crick and Watson thought that she would inevitably find a way to challenge their conclusion.

But they were wrong: their model quickly convinced Franklin. This legitimately surprised them, because they did not expect her to budge. Watson presents Franklin's openness to the model as evidence of how persuasive and elegant it was. And surely, effective scientists have to prioritize data and evidence above their personal relationships with other scientists. Of course, this doesn't always happen—Crick and Watson's relationship with Franklin has been a case in point throughout the book. In fact, readers might also ask whether perhaps what Franklin's acquiescence *really* means is that she was never as "sharp [and] stubborn" as Watson makes her out to be.

Fortunately, by the time my letter reached Cal Tech the base pairs had fallen out. If they had not, I would have been in the dreadful position of having to inform Delbrück and Pauling that I had impetuously written of an idea which was only twelve hours old and lived only twenty-four before it was dead.

Related Characters: James D. Watson (speaker), Max Delbrück , Linus Pauling , Salvador Luria

Related Themes:

Related Symbols:

Page Number: 213-214

Explanation and Analysis

After modeling the first version of the double helix structure, Watson excitedly reported his findings in a letter to Max Delbrück (his doctoral advisor Salvador Luria's collaborator and Linus Pauling's colleague at Caltech). But then, just a few hours later, he realized that this model didn't work. (It depended on hydrogen bonds between identical nitrogenous bases, which would disrupt the DNA molecule's overall structure, and it used the wrong molecular forms for two of those bases.) Watson started to feel like a fool: for the second time, he was enthusiastically talking up an idea that he hadn't even proven yet.

Several days alter, after Watson and Crick *actually* discovered the structure of DNA, Watson received a reply to his letter. Actually, there were two: one from Delbrück and one from Pauling. Both were eager to hear about his new model—but they were referring to the previous model. Thus, ironically enough, while Crick and Watson actually *had* solved the secret to DNA, Delbrück and Pauling were writing to ask about a model they had already discarded. Clearly—and fortunately for Watson—news got around much more slowly in the 1950s than it does today. This appeared to save him from his own pride. Otherwise, he would have repeated his and Crick's previous blunder: boasting about a model that didn't work. Of course, for Watson, this hammered home the importance of humility in science—he now knew to avoid speaking until he was relatively certain about his results. (Unfortunately, he couldn't say the same for Crick.)

Chapter 29 Quotes

Pauling's reaction was one of genuine thrill, as was Delbrück's. In almost any other situation Pauling would have fought for the good points of his idea. The overwhelming biological merits of a self-complementary DNA molecule made him effectively concede the race. He did want, however, to see the evidence from King's before he considered the matter a closed book. This he hoped would be possible three weeks hence.

Related Characters: James D. Watson (speaker), Max Delbrück , Linus Pauling

Related Themes:

Related Symbols:

Page Number: 217-218

Explanation and Analysis

Crick and Watson rushed to solve the mysteries of DNA primarily to beat one man: the world-famous chemist Linus Pauling, who was also studying DNA structure at his Caltech laboratory. And against all odds, they succeeded. They worried that Pauling would be jealous or bitter when he found out, but to their surprise, he reacted with "genuine thrill." Crick and Watson's DNA model was so elegant and so clearly revealed the molecule's function that Pauling didn't feel the need to challenge it. In this way, Pauling's reaction is rooted more in the "thrill" of discovery and the beauty and intrigue of science than on his own personal stake in discovering DNA's structure.

Moreover, it seems, Pauling simply cared more about whether science was advancing than whether he was the person pushing it forward. Thus, Pauling's reply shows the value of mutual respect in the scientific community. In a community where scientists respect one another and care more about the end goal than who achieves it, all competition is friendly because, ultimately, all researchers share the same fundamental objective: better understanding the world.

For a while Francis wanted to expand our note to write at length about the biological implications. But finally he saw the point to a short remark and composed the sentence: "It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material."

Related Characters: James D. Watson , Francis Crick (speaker), Max Delbrück

Related Themes:

Related Symbols:

Page Number: 220

Explanation and Analysis

When Crick and Watson sent off their paper about the double helix model for publication, they debated how much detail to include about their model's implications for DNA replication and genetics more broadly. Their model clearly suggested that DNA could replicate when its two strands separated, each creating a kind of template for new strands to form. They still hadn't proven this replication mechanism, but they believed that at least mentioning it would be essential. Similarly, they strongly believed that their discovery would make a major impact on genetics, but they still couldn't be sure. Therefore, they began debating what to say.

Perhaps unsurprisingly, Crick wanted to give detailed, speculative explanations of his and Watson's thoughts about replication and genetics. But Watson wasn't so sure. In collaboration with other researchers at the lab, they settled on this short, elegant sentence, which allowed them to lay the foundation for future publications—and signal that they understood their discovery's importance—without saying anything for which they didn't have evidence. Ultimately, this debate was really about how much to talk up their own work, or how to appropriately balance pride in their discoveries with professional restraint in presenting them.

Crick's decision to tell anyone and everyone about the double helix was arguably ill-advised—they could have discovered a mistake in their model and ended up looking like fools. Watson's decision to write Max Delbrück about his earlier version of the double helix theory may have been as well, since he very quickly discarded that theory. But Crick and Watson's appropriate restraint in their paper was a resounding success—in fact, this ended up being their paper's most famous line of all.

Epilogue Quotes

All of these people, should they desire, can indicate events and details they remember differently. But there is one unfortunate exception. In 1958, Rosalind Franklin died at the early age of thirty-seven. Since my initial impressions of her, both scientific and personal (as recorded in the early pages of this book), were often wrong, I want to say something here about her achievements.

[…]

We both came to appreciate greatly her personal honesty and generosity, realizing years too late the struggles that the intelligent woman faces to be accepted by a scientific world which often regards women as mere diversions from serious thinking. Rosalind's exemplary courage and integrity were apparent to all when, knowing she was mortally ill, she did not complain but continued working on a high level until a few weeks before her death.

Related Characters: James D. Watson (speaker), Rosalind Franklin

Related Themes:

Page Number: 225-226

Explanation and Analysis

At the end of *The Double Helix*, Watson offers another disclaimer: this book covers his experience alone, and all the people mentioned in it have their own valid perspectives on the race to discover DNA. However, Watson admits that one person can no longer share their perspective: Rosalind Franklin, who died only a few years after the discovery of DNA. Since Watson's comments about her in his book were almost uniformly negative, he tries to do her justice in these final pages. He emphasizes that his perspective on her changed in the final years of her life, and he shows that he deeply respected her work. Perhaps surprisingly, he even acknowledges the challenges that women face in science.

Readers may or may not find Watson's epilogue satisfying. They may disagree about whether Watson's expression of remorse counts as an apology, as well as whether it makes up for the distortions he admits he wrote about Franklin throughout his book. Of course, his admission also raises the natural question of why Watson didn't simply cut out his insulting criticisms of Franklin in the final version. Perhaps most importantly, while he praises Franklin's work, Watson still doesn't recognize that work's important role in making his *own* work possible. In other words, he doesn't point out that his conclusions depended on Franklin's data, he doesn't address the controversy around the way he obtained that data, and he doesn't argue that she deserves greater credit for the discovery of DNA structure. Thus, readers might even question whether this epilogue does more harm than

it does good.

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.

PREFACE

James D. Watson explains that in this book, he wants to capture the human drama of science. Therefore, he has tried to write it from the perspective of his adventurous younger self. He admits that others might remember events differently, but he believes that it's important to tell his story, even if it's incomplete. He also wants to show readers how scientists do their work and negotiate the tension between "ambition and the sense of fair play." To complement his memory of the events, he has revisited old letters and interviewed old friends and colleagues. He thanks them and all the others who have assisted his writing.

Watson opens by setting his readers' expectations. This book isn't a technical explanation of the biology behind DNA, but rather a personal narrative about what it's like to be a scientist and make a major discovery. He emphasizes that this discovery depended on a wide range of colleagues and collaborators, and he also addresses the controversies surrounding his book. Francis Crick, Maurice Wilkins, and several of Watson's other collaborators objected to his plans to publish it, and reviewers and fellow scientists widely criticized his portrayal of Rosalind Franklin. In fact, Watson and Crick's unauthorized use of Franklin's data is still controversial today. This is surely what Watson is referring to when he talks about the tension between "ambition and the sense of fair play." Clearly, he and Crick chose their ambition—and while it paid off, he is not certain that it was the right ethical decision.

INTRODUCTION

Watson remembers meeting his friend Alfred Tissieres in the Swiss Alps in 1955. They ran into the scientist Willy Seeds on a path near their hotel. But instead of stopping to chat, Seeds kept walking by and asked Watson, "How's Honest Jim?" This reminded Watson of his time in England a few years before, when he was searching for the secret of DNA with his colleagues: Maurice Wilkins, Rosalind Franklin, Linus Pauling, and most importantly, Francis Crick.

Willy Seeds's sarcastic greeting—"How's Honest Jim?"—suggests that James Watson developed a reputation for deceit in the years after he and Crick made their great discovery. This probably relates to their use of others' data and ruthless race to solve DNA's structure before anyone else. Seeds worked for Maurice Wilkins, who was also close to discovering the structure of DNA when Crick and Watson published their results in 1953.

CHAPTER 1

"I have never seen Francis Crick in a modest mood," Watson begins. While Crick is famous today, he was unknown when Watson arrived at Cambridge in 1951. At the time, Crick was working in Max Perutz and Sir Lawrence Bragg's Cavendish Laboratory, which studied proteins through X-ray diffraction. Crick did some experiments, but he was mainly focused on the theory of protein structures. He was constantly explaining his new ideas to everyone around him. Most people appreciated his talkativeness and boisterous laughter—except Bragg, who couldn't stand him.

Watson highlights Crick's eccentric personality, sharp wit, and utterly unfocused research agenda. In this way, he portrays Crick as a brilliant underdog trying to prove his worth. This portrait of Crick shows that behind the scenes, research really depends on scientists' personalities and relationships. Watson's problem seemed to be that he was too curious about the truths of the universe to dedicate enough time to any specific problem.

Crick frequently visited other scientists' labs to learn about their experiments and suggest future directions for their research. But many of these other scientists were afraid of him, because they thought he would quickly surpass them and expose their incompetence. Always the nonconformist, Crick also didn't join any of the colleges at Cambridge.

Crick clearly had bittersweet relationships with other scientists and the University of Cambridge as a whole. While he was popular and well-liked, people (and institutions) also kept their distance from him. Crick's outsider status clearly bothered him—but it also gave a greater significance to his relationship with Watson. Moreover, fellow scientists' interest in collaborating with Crick and fear of being upstaged by him show how academics face contradictory incentives: they have to care about scientific discoveries and *their own reputations.*

CHAPTER 2

Crick didn't study DNA before meeting Watson, but he was certainly interested in it. At the time, most scientists thought that genes were protein molecules, but a few—including Crick—thought they were made of DNA. However, Crick's lab was working on proteins, and it would have been too costly and time-consuming to switch to studying DNA instead. More importantly, Crick's friend Maurice Wilkins had already spent years studying DNA. In England—unlike in the U.S. or France—scientists generally considered it disrespectful to step on each other's toes by undertaking similar research. However, Crick also couldn't stand how Wilkins understated his own work's importance.

The scientific controversy about the nature of genes highlights how significant Crick and Watson's discovery truly was: not only did they describe DNA's structure, but in doing so, they also definitively proved its importance to the scientific community. But the limits of Crick's lab also show that social constraints within that scientific community determined whether this research was even possible. Similarly, Crick and Watson's concerns about getting in Maurice Wilkins's way reflect the thorny conflict between the importance of scientists' of research and their ethical obligations to other scientists.

Maurice Wilkins also constantly feuded with Rosalind Franklin, who worked in the same lab as him at King's College London. Watson strongly criticizes Franklin, whom he calls "Rosy" and refers to as Wilkins's assistant. Watson explains that he found Franklin's appearance insufficiently feminine and considered it inappropriate that she wanted to do her own research, instead of just following Wilkins's orders. Watson feels sorry for Wilkins, who had to listen to Franklin complain about sexism at the university. In fact, Watson concludes that Wilkins had to fire Franklin in order to succeed with his research. Wilkins also had to deal with competition from the American chemist Linus Pauling, who wanted to study his X-ray images of DNA.

Watson portrays Rosalind Franklin as practically the opposite of the jovial, collaborative Francis Crick. And yet, while Watson praises Crick's eccentricity and independent-mindedness about scientific problems, he sees these same traits as problems in Franklin. In fact, he primarily judges Franklin for not meeting his expectations of women—that they dress to please men and obediently follow men's orders. Thus, Watson's blatantly misogynistic comments show his readers what kind of hostile environment women scientists had to cope with in the 1950s. But Watson's comments aren't just sexist—they're also plain wrong. He makes basic errors about Franklin's name and position at the laboratory (Franklin didn't go by Rosy and was Wilkins's research partner, not his assistant). It's difficult to say whether these mistakes are intentional, but regardless, they clearly show that Watson didn't take Franklin seriously.

CHAPTER 3

Maurice Wilkins introduced Watson to his X-ray studies of DNA in Naples in 1951, just before Watson met Francis Crick. Watson had just finished his PhD at Indiana University and gone to study the biochemistry of DNA with Herman Kalckar in Denmark. This was ironic, because Watson always hated chemistry—so did his doctoral advisor, the biochemist Salvador Luria, who sent him to Denmark for the DNA project.

Watson's achievements were remarkable in part because of his age. He was just 22 when he earned his PhD and 25 when he and Crick discovered the double helix structure. Like Crick, he clearly saw DNA's importance and wanted to learn more about it. The opportunity to study it was thrilling, at least at first. In fact, after finishing his PhD, he got the opportunity to go on a literal adventure as well as a scientific one. His pathway to Copenhagen again depended on connections and relationships in the scientific community, and it shows the immense opportunities that academic funding can create for the scholars who receive it.

Watson didn't find Herman Kalckar very interesting, and he ended up studying bacterial viruses (or phages) with the scientist Ole Maaløe instead. He felt bad about abandoning Kalckar, but he renewed his fellowship for another year anyway. He felt less guilty after Kalckar started going through a divorce and paying much less attention to his lab. The next spring, Watson's research with Maaløe was going well, so he decided to follow Kalckar to Naples for a couple months and try to learn a bit of chemistry.

Again, Watson struggled to clarify his ethical obligations as a young scientist: was it better to break the terms of his fellowship to pursue more interesting research, or to endure an awful job in order to fulfill the project that was given to him? His decision to pursue his curiosity seemed to pay off, in large part because his fellowship gave him significant freedom to spend his time as he wished. In turn, this freedom allowed him to pursue his interests wherever they led. Still, it's clear that he didn't find his work in Copenhagen satisfying enough.

CHAPTER 4

Maurice Wilkins only went to Naples because his boss was too busy to present their work at a conference. Expectations at the conference were low, since the Italian scientists didn't speak English and the international scientists didn't speak Italian. Meanwhile, Watson was already in Naples, and he wasn't enjoying it. The tiny room he rented was freezing cold, and he still wasn't interested in Herman Kalckar's biochemistry research, which had nothing to do with genetics. He found the conference's X-ray diffraction crystallographers more interesting, but he tried not to get his hopes up, because their work was famously complicated and unreliable.

Watson attended the Naples conference almost on a whim: as a young scientist without a clear direction for his research, he simply wanted exposure to new ideas. In fact, his struggle to identify his research interests was also a struggle to determine his place in the broader scientific community. He knew that he didn't want to simply learn about the properties of the DNA molecule, as Kalckar was doing, but rather understand DNA's specific implications for genetics.

Against all odds, Maurice Wilkins's presentation on X-ray diffraction crystallography astonished Watson. It even included a rudimentary photo of DNA. The next day, Watson found Wilkins during a group excursion and explained his interest in DNA. Wilkins flirted with Watson's sister Elizabeth, who was visiting from the U.S., but didn't follow up about Watson's research interests.

Wilkins's presentation awoke Watson's curiosity and sense of wonder. Tellingly, these passionate feelings—not obligation or self-interest—were the fundamental motive behind his interest in science. Nevertheless, Watson had clearly lost touch with this deeper love for science. And unfortunately, Wilkins didn't seem to see or appreciate Watson's interests when he met Watson in person.

CHAPTER 5

After the conference in Naples, Watson couldn't stop thinking about Maurice Wilkins's X-ray diffraction photo of DNA, the "key to the secret of life." He also learned about Linus Pauling's research on the alpha helix structure of polypeptide chains. Pauling was famously charismatic, and while his presentation on the alpha helix captivated his audiences, nobody knew if he was right. Still, if he was, then this would be most important discovery ever about macromolecule structure. Watson devoured Pauling's articles and imagined writing about groundbreaking discoveries of his own.

Pauling's research was significant because it showed that it was possible to understand molecules similar to DNA by modeling their structure. It represents a theoretical approach to understanding molecules, while Wilkins's X-ray diffraction method represents an experimental approach. But both show that Watson's work ended up relying on earlier scientists' contributions. Watson's fantasy about making a great discovery shows that curiosity wasn't the only thing motivating his research—so were vanity and pride.

Watson concluded that he wanted to start learning about X-ray diffraction crystallography. There were three places he could go: Linus Pauling's lab at Caltech, Maurice Wilkins's at King's College London, or Max Perutz's at Cambridge. Watson chose Cambridge, and Salvador Luria arranged for him to move there, with the help of the Cambridge biochemist John Kendrew.

Again, Watson's professional network opened doors for him all across the world—it was the key to his mobility and success as a young scholar. Meanwhile, Pauling, Wilkins, and Perutz had a complicated relationship: they were all researching the same topics for the same reasons, so they were both competing with one another and constantly improving on one another's work.

Before leaving, Watson went to another conference in Copenhagen. He wanted to learn more about Linus Pauling's experiments from Max Delbrück (Salvador Luria's research collaborator and Pauling's colleague at Caltech). But Delbrück didn't have any insights. Fortunately, though, the conference's parties showed Watson that scientists can have a fun social life.

Watson learned that conferences were as much about building relationships and having fun as actually learning about other scientists' research. In turn, he starts to see the joy and excitement in working as a researcher, which would let him completely mix his professional, social, and personal lives. In other words, he'd get to think and talk about science 24/7.

CHAPTER 6

When Watson first met Max Perutz at the Cavendish Laboratory, he knew nothing about crystallography. But he learned fast. Cambridge's beautiful buildings entranced him—he knew he was in the right place. After the mustachioed, "uncompromisingly British" Sir Lawrence Bragg formally accepted Watson into his lab, Watson visited Copenhagen to tell Herman Kalckar about his plans.

Crystallography, or the study of crystal structure, was significant to biologists because it allowed them to learn about the structure of important molecules like DNA through experiments. Watson's comments about Cambridge's buildings show that he felt a sense of serenity and belonging there. He suggests that the university's physical environment was perfectly suited to foster intellectual growth and discovery.

Next, Watson wrote the Fellowship Board to formally request a transfer to Cambridge. But the Board refused—Watson wasn't qualified for crystallography work. Watson then wrote Salvador Luria, who was friends with the Board's new chairman, to ask for help. At Luria's suggestion, Watson proposed collaborating with both Max Perutz and the Cambridge plant biochemist Roy Markham. But the Fellowship Board merely wrote back to say it was considering Watson's petition. Fortunately, Watson had plenty of savings from his time in Copenhagen, so he went ahead and installed himself in Cambridge. When his landlady kicked him out, he moved into a room in John Kendrew's house.

Watson's unfamiliarity with crystallography again shows how surprising and unlikely his and Crick's discovery was. While scientists like Maurice Wilkins had been doing crystallography experiments on DNA for years, Watson and Crick were practically untrained in the field. Still, despite his inexperience, Watson's connections again saved him—they gave him the freedom to follow his curiosity to Cambridge. Of course, his generous fellowship also made a huge difference. This again shows how scholars' intellectual and scientific work really depends on whether institutions meet their day-to-day material needs.

CHAPTER 7

As soon as Watson met Francis Crick, he knew he wanted to stay at Cambridge. They were both enthusiastic about DNA, and they thought they could discover its structure before Linus Pauling. They spent endless hours talking, and Crick explained Linus Pauling's alpha helix research to Watson. Pauling's discovery wasn't based on equations or X-ray diffraction, but rather on a straightforward analysis of how different atoms fit together, using **molecular models**. Watson and Crick realized that they could do the same thing with DNA.

Watson and Crick's friendship was the foundation for their research. In turn, their friendship depended on their shared curiosity about DNA, similar scientific ambitions, and compatible personalities. These factors didn't just amuse or delight Watson—rather, they gave him a deep sense of purpose and belonging. On another note, Linus Pauling's alpha helix research was a suitable model for Crick and Watson's work because it was essentially theoretical. In other words, Pauling's work showed Crick and Watson that they could bypass experimental work entirely and simply use logical deduction to build a molecular model of DNA. This was welcome news because they didn't have the time, experience, or resources to perform complex experiments.

Watson and Crick started building **molecular models** and trying to fit them together in a helix (the simplest and most likely structure for DNA). Based on the tight DNA crystals that Maurice Wilkins and Rosalind Franklin studied, Watson and Crick assumed that DNA probably included multiple long chains of nucleotides, which were twisted and bonded together. They also knew that DNA contained four different nucleotides, which had the same phosphate and sugar groups (so they would bond in a consistent way) but different nitrogenous bases (so they would be distinct from one another). This was perfect for a helix structure: the nucleotides could all have the same kind of bond but occur in the very irregular order that's necessary for a series of genes to form a code.

Readers might assume that little was known about DNA when Watson and Crick started studying it, but this wasn't the case at all. In fact, when Watson and Crick started their research in 1951, scientists had known about and been conducting experiments on DNA for almost a century. These earlier experiments were the foundation for Crick and Watson's research—as this section shows, earlier work allowed Crick and Watson to make a number of key assumptions about DNA's structure. However, Watson and Crick didn't just want to explain how DNA was structured—they also wanted to prove that it was the key genetic material. In order to prove both these points, they had to solve a crucial puzzle: how can DNA be a regular molecule that forms the same shape in every organism and yet encode irregular genetic information that is different in every organism?

Watson and Crick also knew that they could eliminate plenty of possible structures for DNA if they had good X-ray pictures of it. But the only person with these pictures was Maurice Wilkins. Fortunately, Wilkins was happy to visit them at Cambridge. He explained that he also thought DNA was a helix, but he spent most of his time talking about his worsening feud with Rosalind Franklin. She wouldn't even share her results with him anymore. The three men agreed to attend her upcoming talk.

While Watson and Crick didn't want to do experiments on their own, Wilkins and Franklin's X-ray data could give them key measurements and help refine their DNA model. While Crick and Watson's close friendship launched a fruitful research partnership, Wilkins's conflicts with Franklin were clearly preventing him from doing successful research. Both of these cases prove that personal and professional relationships are incredibly important to effective scientific research, even though they might seem incidental to it at first.

CHAPTER 8

A week after the meeting with Maurice Wilkins, Francis Crick got into a furious argument with his bosses, Max Perutz and Sir Lawrence Bragg. Crick alleged that Perutz and Bragg used one of his ideas in their paper without crediting him. Fed up, Bragg threatened to fire Crick once he finished his PhD.

Crick's fight with Bragg shows how his eccentric personality and constant flow of new ideas are actually a liability for his lab. But Crick's grievance also points to the ethical importance of properly attributing original ideas to the people who created them and data to the people who collected them.

Watson notes that Bragg had a point: despite his brilliant ideas, Crick hadn't produced any real scholarship. When World War II broke out, he was getting a PhD in physics, and he went off to research for the government. But after the war ended, he switched to biology. That's how he ended up at the Cavendish Laboratory, 35 years old and without a PhD. Fortunately, Max Perutz and John Kendrew convinced Bragg to keep Crick on at the lab.

Crick couldn't have taken a more different path than Watson (who was still underage during World War II and earned his PhD at just 22). In fact, Crick's unconventional path put his entire academic career in peril. Watson clearly implies that Crick's DNA research threatened to distract him from his doctoral work even further. Thus, Crick faced a difficult choice between pursuing a secure career and following his unusual interests.

CHAPTER 9

A few days after Crick's explosive argument with Sir Lawrence Bragg, the crystallographer V. Vand wrote Max Perutz to explain his new theory of how to use X-ray diffraction to study helices. Crick and his colleague Bill Cochran immediately noticed errors in Vand's theory, so they tried to correct it. Later that day, Crick figured out the solution while sitting home by the fireplace.

Vand's crystallography theory had clear applications to DNA: if X-ray diffraction could identify helices, then Crick and Watson could use it to prove that DNA was a helix. Crick corrected Vand's theory during his time off in the evening, which reveals his brilliance and shows that he was always obsessively following his curiosity about science—even if he couldn't focus that curiosity toward his thesis research.

Crick lived in a cramped but cozy apartment with his second wife, Odile, who shared his disdain for the middle class, politics, and religion. She was also a great cook, which Watson attributes to her French mother, and she didn't mind that her husband constantly chased other, younger women.

Crick's quaint home life with Odile clearly fit his unusual personality and interests. Watson views this as the truly extraordinary part about academic life: scholars get to fully immerse themselves in their ideas and research, without stooping down to the level of ordinary middle-class preoccupations. But Crick's intellectual freedom is inseparably tied to Odile's role as a housewife whose social life is entirely dependent on her husband's. This raises an important question: when scholarly life is only possible because of other people's labor, can those other people ever be as free as the scholars they support?

The afternoon after Crick's discovery, he and Odile went to a wine tasting, but unfortunately there were no younger women there. The next morning, he learned that Bill Cochran found the same solution as he did, but in a more elegant way. Delighted, they quickly published their results, then sent a copy to Linus Pauling.

Crick and Cochran's improvement on Vand's theory also shows that science is a cumulative, collaborative process. In other words, scientists make progress by working together, integrating their ideas, and checking one another's data and hypotheses.

CHAPTER 10

In November, Watson attended Rosalind Franklin's talk about her crystallography results. He disliked her dry speaking style and wished that she did her hair differently. Whereas Linus Pauling discovered the alpha helix with **molecular models**, Franklin strongly believed that crystallography was the only way to discover the structure of DNA. But she believed that scientists needed much more data before they could figure it out. The audience said little and asked few questions. Watson speculates that they wanted to avoid Franklin's "sharp retort[s]."

Watson's again evaluates Franklin primarily by her appearance and attitude, and not the quality of her research. Needless to say, his perspective on her is far from objective. Still, if Franklin really believed that only crystallography could solve the structure of DNA, then she was clearly underestimating the significance of Pauling's work. This shows that when scientists refuse to take one another's work seriously—whether out of spite, ignorance, or pride—they often miss out on the greatest truths and discoveries. In other words, science is most effective when researchers collaborate and least effective when they insist on working alone.

At dinner that evening, Maurice Wilkins was delighted about how little progress Rosalind Franklin had made. Watson notes that Wilkins was no longer the aloof, indifferent scientist he first met in Naples. Actually, Wilkins appreciated Watson's encouragement because he was "a phage person." Unlike most physicists, biochemists, biologists, and other geneticists, Watson understood the importance of DNA.

Wilkins's attitude toward Franklin—like the audience's response to her during her presentation—suggests that Watson wasn't the only person who strongly disliked her. This underlines how difficult it must have been for Franklin to succeed in such a male-dominated profession in the 1950s. Meanwhile, Wilkins finally noticed that Watson took DNA as seriously as he did and approached it from a similar angle. Physicists knew nothing about biology, biochemists and biologists knew nothing about genetics, and geneticists weren't interested in studying molecules. But the "phage people," like Max Delbrück and Salvador Luria, clearly saw the link between DNA and genetics based on experimental evidence.

CHAPTER 11

The morning after Rosalind Franklin's talk, Watson met Crick at the train station. They were heading to Oxford, where Crick wanted to explain his and Bill Cochran's new theory to the crystallographer Dorothy Hodgkin. On the train, Crick asked Watson all about Rosalind Franklin's talk—but Watson didn't remember many important details. He comments that Crick probably should have gone to Franklin's talk instead of him, even if Crick's interest in the subject might have bothered Maurice Wilkins. Watson notes that while Wilkins deserved the first shot at analyzing Franklin's data to figure out DNA's structure, he was still trying to do it through crystallography alone. In contrast, Crick and Watson wanted to use **molecular models**, like Linus Pauling.

Crick's meeting with Dorothy Hodgkin shows that, despite his inexperience and slow progress on his dissertation, he was still making significant scientific discoveries. Watson recognized this: he admitted that he didn't understand much of Rosalind Franklin's talk and that Crick was far more advanced than him at crystallography. Meanwhile, Watson and Crick continued to struggle with the ethical implications of doing similar research to Franklin and Wilkins. At what point, they ask, does collaboration turn into theft? Would they be able to make discoveries that Wilkins and Franklin never would, because they weren't willing to use molecular models? Arguably, Watson and Crick succeeded because, as newcomers, they were actually willing to try new, innovative techniques that more established scientists would reject.

On the train, Crick had a flash of insight and started scribbling away on scratch paper. He pointed out that if Rosalind Franklin's data was right, but so was his and Bill Cochran's theory, then there were only a few options for DNA structure: it had to have either two, three, or four strands. Crick thought they were already close to a solution. This would be a great win for Cambridge—after all, everyone (especially Sir Lawrence Bragg) felt humiliated by Linus Pauling's recent success.

Right on the heels of one discovery, Crick immediately began chasing another. Again, his central motivation was sheer curiosity—and the license to follow this curiosity is clearly what Watson considers so extraordinary about a scientist's life. However, Watson acknowledges that competition and pride also motivated Crick—and everyone else in their lab. As always, there was a fine line between collaboration and competition in the scientific community. For instance, even as he hoped to beat other people to the structure of DNA, Crick was still relying on those people's research (namely, Franklin's experimental data).

Based on Maurice Wilkins and Rosalind Franklin's X-ray diffraction data, Crick and Watson quickly concluded that "the sugar-phosphate backbone was in the center of the [DNA] molecule." However, they still had to figure out how the nitrogenous bases could both have an irregular sequence and face outward. Moreover, they had to figure out what positive charges neutralized the negative charges in the molecule's sugar-phosphate backbone. The expert on this latter topic was none other than Linus Pauling, so when they arrived in Oxford, Crick and Watson quickly bought and read a copy of Pauling's book *The Nature of the Chemical Bond*.

Readers might find this sudden rush of molecular biology concepts overwhelming. Of course, by presenting them in this way, Watson also replicates the feeling of his and Crick's rush of theoretical insights. To understand Crick and Watson's conclusions, it's essential to know that DNA is made up of nucleotides, *which are compounds with three components: nitrogenous bases, a phosphate group, and a sugar. Crick and Watson believed that the sugar and phosphate group form a chain, or backbone, that simply holds the DNA molecule together. Meanwhile, they believed that the nitrogenous bases (generally coded as A, T, C, and G) carry genetic information, depending on their order in any given strand of DNA. These assumptions weren't just shots in the dark: they were based on experimental evidence that revealed the different components of DNA. While other scientists didn't necessarily agree with them, they ended up being correct. Based on these assumptions, Crick and Watson then asked how the sugar-phosphate backbone and nitrogenous bases were oriented toward one another. But at this point, they were making educated guesses based on their knowledge of chemistry. Their recourse to Linus Pauling's book shows that they were not nearly as knowledgeable about this topic as their rivals.*

It was time for Watson and Crick's meeting with Dorothy Hodgkin, so they temporarily put the mystery of DNA aside. At the meeting, Crick explained his and Bill Cochran's results, and then Hodgkin discussed her work on insulin. Next, Crick and Watson met their friends Avrion Mitchison, Leslie Orgel, and George Kriesel for tea and dinner.

Crick and Watson got to spend their lives alternating between their two great passions: intense scientific work and casual socializing. Of course, these two weren't totally distinct—their scientific work was collaborative, and they mostly talked about science when they socialized.

CHAPTER 12

Back in Cambridge, Watson explained his and Crick's new findings to John and Elizabeth Kendrew over breakfast. Then, he rushed back to the lab. He and Crick needed new **molecular models** for their research on DNA, but it would take too long to get them constructed, so Watson started modifying their existing ones instead.

Watson's excitement about his and Crick's DNA research was palpable: he wanted to advance as much and as fast as he could. His enthusiasm in the lab showed that a year after finishing his PhD, he finally found a project that truly mattered to him.

At lunch, Crick usually theorized about muscle proteins with his friend Hugh Huxley, but that day, he was intensely focused on DNA. He and Watson discussed whether DNA was likely to have two, three, or four strands. Then, they speculated that magnesium or calcium ions were most likely to neutralize the phosphate groups.

Crick's tendency to theorize over lunch shows yet again how he didn't really distinguish work from leisure—he was always working on scientific problems, no matter what. It also shows how his scientific pursuits largely depended on discussion and collaboration with other researchers.

After lunch, Watson and Crick started experimenting with their makeshift **molecular models**. They quickly ran into a problem: the bonds between the different nucleotides in DNA could take any shape, which made determining the molecule's structure difficult. But still, they made progress, and the quickly developed a three-chain structure consistent with Maurice Wilkins and Rosalind Franklin's crystallography data. At dinner, Watson and Crick discussed their findings with Crick's wife, Odile. She was delighted to hear about their progress, but she didn't understand much about science, so conversation turned to a family friend's upcoming marriage.

While Crick and Watson appeared to be making progress, their enthusiasm was clearly premature. In reality, they were still grappling with relatively elementary questions about DNA—like how many strands it has and what shape it takes. Although they did build one viable DNA model, they didn't eliminate all of the other possible models. The reader likely already knows that DNA really has two chains, not three. Meanwhile, Odile Crick's lack of knowledge about her husband's work again suggests that Cambridge was strictly divided according to gender, with (mostly) men doing important scholarly work and (mostly) women doing the day-to-day labor that made this scholarly work possible.

The next day, Watson and Crick significantly improved their three-helix model. The next step was to compare it to Rosalind Franklin's crystallography data. They called Maurice Wilkins. Although he sounded uninterested on the phone, he visited Cambridge the next day with his colleague Willy Seeds, Rosalind Franklin, and Franklin's student R.G. Gosling.

Crick and Watson believed that they had made real progress toward a major discovery about the nature of life and heredity. Despite his aloof personality, Wilkins clearly took Crick and Watson seriously—otherwise, he wouldn't have visited. Still, Crick and Watson's model was purely theoretical, and they knew they needed some experimental data to back it up. Thus, despite all their ill will toward her, Rosalind Franklin would actually prove essential to their work.

CHAPTER 13

In the morning, Maurice Wilkins, Rosalind Franklin, Willy Seeds, and R.G. Gosling visited Cambridge, where Crick and Watson explained their theory. But their visitors weren't amused. Wilkins noted that his colleague already calculated that DNA must be a helix, while Franklin argued that there was no empirical evidence for a helical structure at all.

Apparently, Crick and Watson's work wasn't as original or insightful as they hoped. In fact, Wilkins and Franklin's attitudes suggest that they viewed Crick and Watson as wasting their time. Plus, Wilkins and Franklin's strong disagreement about DNA's shape made it difficult for Crick and Watson to learn anything meaningful from their initial comments.

Rosalind Franklin also noted argued that magnesium ions wouldn't be able to hold DNA together. Worse still, Watson realized that he misquoted the water content of Franklin's DNA samples to Crick. This mistake led the duo to wrongly eliminate many possible models. Over lunch, everyone agreed that Crick and Watson should next investigate whether there are magnesium ions in DNA. But their findings clearly weren't going to change their visitors' research agendas. Back in the lab, Crick and Watson started to see their **molecular model** as worthless trash. Their visitors rushed off to the train station.

Crick and Watson's first model wasn't simply plausible but unoriginal—rather, it was seriously flawed to the point that it was chemically impossible. As their meeting with Franklin and Wilkins started to collapse, Crick and Watson began to evaluate how they went wrong. Ultimately, they ended up humiliating themselves before their senior colleagues because they let ambition, arrogance, and enthusiasm cloud their judgment. In fact, Crick and Watson's overconfidence is another important sign that science really depends on people's whims and emotions, even if it's supposed to arrive at clear and objective results.

CHAPTER 14

Sir Lawrence Bragg grew furious when he learned about Crick and Watson's unsuccessful meeting with Maurice Wilkins and Rosalind Franklin. In fact, Bragg worried that he might have to deal with Crick for the rest of his career, because Crick might never finish his PhD. Thus, he declared that Crick and Watson had to stop working on DNA. This would give Maurice Wilkins his fair shot to study it first, and it would give Crick time to finish his PhD.

Crick and Watson's failure didn't just embarrass them: it also harmed their entire lab's reputation. Thus, Bragg saw their forays into DNA research as not just foolish but also deeply selfish. While Crick and Watson were too busy dreaming about fame to think through their decision, Bragg suggests, responsible scientists evaluate their decisions' personal and professional consequences before they act.

Crick and Watson agreed to stop researching DNA. After all, they had already realized that their model simply didn't work because it was impossible for the sugar-phosphate backbone to fit in the middle of the helix. Plus, they couldn't expect Maurice Wilkins and Rosalind Franklin to share data with them anymore. They gifted Wilkins and Franklin their **molecular models**, knowing that they wouldn't get used.

Crick and Watson failed in part because they underestimated the complexity of the problem that they faced. However, their failure also led them to important insights—for instance, if they decided to continue working on DNA later, they could now discard models with the sugar-phosphate backbone in the middle. Crucially, they also realized that their mistake hurt key professional relationships. They understood how this would affect their ability to collaborate with other scientists in the future. Thus, they began to clearly see how relationships form the foundation for good science.

Crick and Watson concluded that nobody would be cracking the code of DNA anytime soon, at least in the UK. Crick returned to his thesis research on proteins, while Watson started studying theoretical chemistry. But during their free time, they kept talking about DNA. For Christmas, Crick gave Watson a copy of Linus Pauling's book *The Nature of the Chemical Bond*.

Crick and Watson quickly lost the sense of purpose and excitement that came with their DNA research. In particular, once Watson put this short-term thrill aside, he had to start thinking about a sustainable, long-term direction for his career. Meanwhile, Crick's ordinary research was slow-paced, predictable, and relatively unlikely to change the world. Clearly, both Crick and Watson had to find a balance between these the two sides of science: the high-stakes world of DNA and the boring but stable world of ordinary lab experiments.

CHAPTER 15

For Christmas, Watson went to Avrion Mitchison's parents' house in the Scottish fishing village of Carradale, where they always invited a mix of scientists and left-wing intellectuals over for the holidays. His sister Elizabeth also visited from Denmark, where—to Watson's horror—she was dating an actor. In Carradale, Watson spent most of the time trying to keep warm. He tried (and failed) to grow a beard, and he tried to avoid getting noticed during the nightly board and party games.

Watson's Christmas vacation wasn't truly a break from intellectual life—rather, it gave him an opportunity to meet others with same high-minded interests. Again, this shows that the scholarly life is really just as personal as it is professional. It's also related to class: when Watson left the comfortable bubble of Cambridge, he could clearly see that he now belonged to a powerful, privileged elite. And yet, despite his academic pretensions, Watson clearly shared the preoccupations of any ordinary young man—he worried about being popular, growing a beard, and withstanding the Scottish winter.

Watson returned to Cambridge on a snowy January 4th. He was hoping for news about his fellowship, but there was none. A few weeks later, he learned that the Board was taking away his old fellowship but giving him a new one. However, it only lasted eight months instead of twelve. A few days later, the Board's chairman wrote asking Watson to give a lecture about viruses in June. But Watson didn't want to go back to the U.S., so he declined.

Like his and Crick's argument with Sir Lawrence Bragg, Watson's issues with his fellowship showed that he needed to find a balance between freedom and responsibility. On the one hand, he wanted to preserve his freedom to study what he wanted; but on the other, he had to stay within certain bounds in order to get funding. The new, shorter fellowship was clearly a kind of punishment for Watson's decision to leave Copenhagen and abandon his earlier research without due cause. However, he was lucky to receive it at all—although he had been surviving on his savings, he likely couldn't continue his research with Crick without another fellowship.

CHAPTER 16

Watson spent his days at the Cavendish Laboratory studying TMV, or tobacco mosaic virus. He chose it because one of its main components was RNA, which is closely related to DNA. Before World War II, the crystallographers J.D. Bernal and I. Fankuchen had done interesting work on TMV's structure, and they knew that it was made of many repeated subunits. By the 1950s, scientists knew that proteins could have lots of subunits, but RNA couldn't. Therefore, Watson hypothesized that TMV was made of many identical protein subunits surrounding a core strand of RNA. A Nazi-funded German scientist had come to the same conclusion in 1944, but non-German scientists didn't trust his data.

TMV offered a good middle ground between Watson's previous research on viruses and his new interests in DNA and crystallography. (Of course, his fellowship money was also designated for TMV research.) Determining TMV's structure would mean solving a similar problem to DNA's structure with a similar set of tools. Of course, both projects also required him to understand and interpret other scientists' data in light of later discoveries. For instance, he could interpret Bernal and Fankuchen's images in the light of more recent advances in crystallography.

Watson eagerly showed Bernal and Fankuchen's X-ray diffraction photo of TMV to Crick, who agreed that it appeared to have a helical structure. Watson started to theorize that TMV probably grows irregularly, like crystals, which means its shape is probably helical. Hugh Huxley gave him an X-ray camera and taught him to take diffraction images, and Roy Markham found him TMV samples to study. But it took Watson more than a month to get any reasonable pictures of TMV, and even then, he had a long way to go before he could see a helix. At least he attended a fun costume party around this time.

The helical structure of TMV was also an important similarity to DNA—it suggested that Watson's research could indirectly prepare him to learn more about DNA. After all, while he clearly started to become more enthusiastic about TMV, he was still really thinking about DNA. His struggle against the X-ray camera helps explain why he and Crick were so attracted to theoretical research, as opposed to experimental research. Namely, experiments are far more time-consuming and labor-intensive than theory. Of course, theory still needs data to interpret, so someone has to conduct the experiments.

CHAPTER 17

Linus Pauling was supposed to visit London for a conference that May, but U.S. State Department revoked his passport because of his peace activism. This scandalized London's scientific establishment, but it didn't surprise Watson—a few weeks before, the same thing had just happened to Salvador Luria, who was supposed to attend a virology conference at Oxford. Watson went in Luria's place.

The U.S. government's treatment of Pauling and Luria shows how Cold War politics strongly shaped science in the 1950s. But, in part because politics started to take over science, science also gained the power to shape politics. Even if their work may have seemed obscure and cut off from the world, researchers actually had influence in the international community.

At the conference, Watson explained Al Hershey and Martha Chase's recent research showing that phages infect bacteria using DNA. This proved that DNA is the key genetic material. Most of the audience was uninterested, but a trio of French virologists clearly understood the experiment's significance. One of them, André Lwoff, shared Watson's hunch that ions were probably key to understanding the structure of DNA. Meanwhile, Maurice Wilkins confirmed that he and Rosalind Franklin hadn't touched Crick and Watson's **molecular models**, and he promised to send them back. He also reported that Franklin thought she'd proven that DNA couldn't be a helix.

Hershey and Chase's phage research was extremely significant, so it's no surprise that the audience's ambivalence disappointed Watson. Hershey and Chase disproved the common scientific belief that proteins were the key to genes—instead, they showed that Crick, Watson, and others in their network were right to focus on DNA. It's also significant that Watson ended up attending this conference to present someone else's *transformative research on DNA. This represents how he ended up on the sidelines of the research he truly cared about, even as others were taking it forward without him. At the same time, Wilkins and Franklin's reluctance to use the molecular models suggests that DNA research couldn't truly succeed without Crick and Watson. Clearly, they were itching to get back to it.*

CHAPTER 18

Watson soon got ahold of a powerful new X-ray tube, which let him take pictures much faster. One summer night, he got the picture he wanted: it clearly proved that TMV was a helix. In the morning, Crick confirmed Watson's finding. Watson was delighted, but he also knew that he wasn't prepared to study TMV any further.

Watson's finding demonstrates the psychological rewards of good science: he felt excited by and satisfied with his work. Nevertheless, he still knew that there was another, far more interesting and significant problem out there for him to tackle: DNA.

Instead, Watson started talking to Crick about the biochemist Erwin Chargaff's discovery that most DNA tended to have around the same amount of adenine (A) as thymine (T), and the same amount of guanine (G) as cytosine (C). At first, Crick wasn't interested at all, but he changed his mind when talking with his friend John Griffith, a theoretical chemist. They were discussing the lively debate about whether genes replicate by directly copying themselves, or by creating a complementary surface—a kind of negative image or mold that can then be filled to make more copies of the same gene. Crick and Griffith wondered if they could find an answer by studying bonds. A few days later, Griffith explained that his calculations indicated that adenine and thymine should stick together, as should guanine and cytosine.

Chargaff's discovery is another example of how DNA science was advancing rapidly while Crick and Watson were busy with other research. The nitrogenous bases adenine, thymine, guanine, and cytosine were significant for Watson and Crick because they were the unique elements in DNA that seemed capable of encoding genetic information. In other words, if scientists could figure out how these four bases worked, they could determine how DNA carried genes. Indeed, readers who are familiar with DNA's structure and function may immediately understand the significance of Chargaff's research and Griffith's calculations. Chargaff's research suggests that adenine and thymine probably pair together, as do guanine and cytosine. Griffith's calculations suggest that this pairing is chemically possible. In several chapters, Watson will discover how these pairs encode genes. This also explains how DNA copies itself (although, in reality, it's through a mix of complementary surfaces and direct replication). The problem of gene replication is significant because, in order for beings to develop from collections of cells into complex organisms with the same genes in every cell, they have to multiply their genetic material somehow. Therefore, a satisfactory model of DNA would have to explain not only what it's made of but also how it encodes genetic material and replicates itself.

Crick and Watson realized that John Griffith's calculations fit perfectly with Erwin Chargaff's discovery. However, Griffith wasn't too confident in his calculations, and Roy Markham believed that Chargaff's methodology was unreliable. In fact, Chargaff was about to visit Cambridge, so John Kendrew set up a dinner with him, Crick, and Watson. However, Chargaff quickly decided that the disheveled, long-haired Watson was a lunatic, and that the overconfident Crick didn't know anything about DNA. Crick brought him a copy of Griffith's calculations the next day.

Crick and Watson's tense dinner with Chargaff again reveals the stark difference between the way they viewed themselves and the way everyone else viewed them. While they thought they were on the cutting edge of DNA research, most of the senior scientists they met viewed their ideas as naive and delusional. After all, Crick and Watson still hadn't done any DNA experiments of their own—so far, they had only learned about other people's experiments.

CHAPTER 19

A few weeks later, Watson attended the International Biochemistry Congress in Paris. He briefly passed Erwin Chargaff, then went to meet Max Delbrück, who had offered him a job at Caltech (but helped him get another year's fellowship at Cambridge instead). However, Delbrück wasn't particularly impressed by Watson's TMV research or the DNA models he put together with Crick. Linus Pauling also got his passport back and went to the conference. While his talk was packed full of spectators, he really just summarized his existing research.

The International Biochemistry Conference again shows that even when scientists do their own individual research, science is always a cumulative, collaborative process. The Conference allowed the whole international community of biochemistry researchers to assemble, understand the state of their field as a whole, learn about new ideas, and improve their existing ones. Meanwhile, senior scientists continued to question the value of Watson's work, showing him how far he still had to go in order to be taken seriously as a researcher.

After the conference, Watson followed other phage researchers to Royaumont Abbey near Paris, where they were assembling for a week. He also invited Maurice Wilkins, who didn't enjoy the conference and was on his way to go teach in Brazil. But Wilkins got sick and left after one night. At Royaumont, Watson managed to chat with Linus Pauling, but only about his virus research and his plans to go to Caltech. He had a longer conversation with Linus's wife, Ava Helen, who explained that her son Peter was going to do his PhD with John Kendrew at Cambridge. Watson comments that Peter wasn't as interesting as his attractive sister, Linda. The phage researchers' meeting ended with an extravagant party at a baroness's country mansion.

The stay at Royaumont Abbey and party with the baroness are clear examples of the great privileges that academic life gave Watson. Of course, to Watson, meeting Linus Pauling was the greatest privilege of all. But in addition to being one of the most famous scientists in the world, Linus Pauling was also the Cavendish Lab's most important competitor in DNA research besides Maurice Wilkins. Moreover, the personal connection between Linus Pauling, Peter Pauling, and John Kendrew is a reminder that the scientific community isn't an abstract idea: rather, it's a network of real people who know, work with, write to, and sometimes even love one another. And in some cases—like Peter Pauling going to study with his father's rivals in Cambridge—this mix of personal and professional can create complicated conflicts of interest.

CHAPTER 20

Watson spent the fall researching how bacteria reproduce. At a conference in Italy in September, he learned that the precocious 22-year-old Joshua Lederberg had just proven the existence of male and female bacteria—but still hadn't determined how they mated. At the conference, Watson and Lederberg's collaborator, Bill Hayes, speculated about whether the male and female bacteria contribute equally to the offspring's genetic material. Back at Cambridge, Watson tried to interpret Lederberg's data.

Watson's bacteria research is actually closely related to his work on TMV and DNA. Bacteria mating could tell scientists about how biological parents' genes mix in their offspring. This was one of the greatest mysteries in genetics in the 1950s. Watson's approach is similar to how the phage researchers understood the function of DNA by studying how viruses use it to infect bacteria.

Meanwhile, Crick wanted to get back to DNA. Between his thesis research, he was trying to test his hypothesis about adenine's attraction to thymine and guanine's attraction to cytosine. He went to discuss this with Maurice Wilkins in London, but they got distracted at lunch, and he ended up forgetting to mention it. The next day, he tried to convince Watson to try modeling the DNA structure again. But Watson thought they weren't ready—they hadn't even started the experiments to look for magnesium ions.

Sir Lawrence Bragg could make Crick work on proteins instead of DNA, but he couldn't prevent Crick from thinking *about DNA. The mystery of DNA continued gnawing at Crick, who still believed that he could succeed if he took another shot at it. He began trying to convince Watson to join him because he knew that scientists were constantly publishing new results about DNA, but also that he couldn't discover its structure alone.*

Watson was relieved to learn from Peter Pauling that Peter's father, Linus, wasn't studying DNA—he was researching "coiled coils" (how alpha helices coil together in proteins like keratin). However, Crick was *also* studying coiled coils, so he paused his thesis research to work out and publish his equations before Pauling could do the same. In fact, other researchers started taking note of Crick, and he got a generous fellowship to spend the following academic year studying the ribonuclease enzyme in Brooklyn. Meanwhile, Watson kept studying bacterial mating. He discussed it with Bill Hayes, and DNA with Maurice Wilkins, whenever he visited London.

When Peter Pauling arrived at Cambridge, he effectively set up a line of communication between the Cavendish Lab and Linus Pauling. Again, this shows how science fundamentally depends on personal relationships. And yet these relationships involve a complex mix of collaboration and competition. For instance, even though much of Watson's research was indebted to Pauling, he also raced to publish his results before Pauling in order to receive greater recognition for his work. Crick's recognition, meanwhile, reinforced the idea that sheer intelligence, passion, and insight were the most important traits in a scientist—and that others would overlook Crick's unusual personality and history.

CHAPTER 21

Watson joined Cambridge's Clare College, since this allowed him to live in a dormitory. But he couldn't stand the college's food, so he generally ate out—until he started getting stomach pains from eating too much foreign food. The doctor wasn't very sympathetic and just gave him a bottle of white medicine that didn't work. The same night as his visit to the doctor, he also visited Francis and Odile Crick at their new house. They helped him with his plot to enter the boarding house where the French girls stayed on their exchange programs.

Watson was much younger than most of his colleagues, including Crick, and he didn't have an established family or social network when he arrived at Cambridge. Therefore, a year into his time there, his feelings about his social life were clearly mixed. On the one hand, everything was taken care of for him, and he got to pursue his passion all day. On the other, he was also lonely, and he never had a break from work to do anything else.

Back at home, Watson read new biochemistry papers about protein synthesis and DNA. He strongly believed that DNA was the template for RNA, and that RNA was the template for proteins. But as he drifted to sleep, he realized that he hadn't gotten any closer to the secret of DNA over the last year. He and Crick discussed it once in awhile, but they mostly focused on their separate research. Otherwise, Watson spent plenty of time discussing girls with Peter Pauling. One day, however, Linus Pauling sent his son a letter declaring that he'd figured out the structure of DNA. Crick and Watson initially declared that they should try to figure out the structure, too, and publish it at the same time as Pauling—but they quickly started to lose hope.

Watson had just rejected Crick's offer to start working together again on DNA, but he was also clearly fixated on it. Both Crick and Watson still felt a sense of curiosity and wonder at DNA, which they believed could unlock the secrets of genetics, heredity, and identity. And they both knew that their time was limited, because someone *would eventually solve the secret of DNA. Therefore, Linus Pauling's letter was a rude wake-up call: it suggested that by following Bragg's orders and suppressing their own curiosity, they had probably given up their only chance to discover the secret of life.*

CHAPTER 22

For the rest of the year, Linus Pauling didn't reveal anything more about his DNA experiments. So, Crick and Watson started to hope that maybe Pauling didn't truly have the right structure figured out. In London, Maurice Wilkins told Watson that Rosalind Franklin was finally leaving his lab and stopping her research on DNA. Then, Peter Pauling got another letter in January: his father had written up his results and would be sending a copy to Cambridge. In fact, he sent two—one to his son and one to Sir Lawrence Bragg. Bragg decided not to show it to Crick, so as not to distract him from his thesis, but Peter showed Watson and Crick his copy.

As their rivals pushed ahead with DNA research, Crick and Watson struggled to figure out if and how they could contribute to it. Again, Peter Pauling's influence on them was absolutely crucial—although he didn't give them new ideas, he kept them informed about his father. In fact, Crick and Watson likely would have never returned to DNA research if Peter hadn't shown them his father's research. This again shows that even when major scientific discoveries seem like works of individual genius, they may actually depend on unlikely relationships and even total coincidences.

Peter Pauling explained that his father modeled DNA as "a three-chain helix with the sugar-phosphate backbone in the center"—almost exactly what Watson and Crick thought a year before. But when Watson studied Linus Pauling's diagrams, he realized that there was a major problem. In his model, Pauling neutralized the phosphate groups' negative charges with an extra hydrogen atom. But according to the rules of basic chemistry, this never happens—after all, it would mean that DNA is neutrally charged, not an acid. Pauling might have been challenging the basic principles of chemical theory, but more likely, he just made a huge mistake.

In the early 1950s, Linus Pauling was easy the most influential chemist in the world. Crick and Watson depended on Pauling's book during their first attempt to model DNA, and Watson felt incredibly honored to meet him at the International Biochemistry Congress in Paris. Therefore, it makes sense that Crick and Watson were totally astonished at Pauling's basic oversight. In fact, this oversight showed Crick and Watson that they were just as capable as their idols: if they could make the same errors as Pauling, then they could also surely make great discoveries like him, too.

Watson started running around Cambridge to talk with other colleagues—and all of them agreed that Pauling was wrong. Meanwhile, Crick tried to persuade John Kendrew and Max Perutz to let him work on DNA again. He and Watson wanted to find the structure before Pauling could identify and correct his error. Watson planned to show Maurice Wilkins the manuscript a few days later in London. But first, he and Crick celebrated Pauling's mistake with a drink at their favorite pub, the Eagle.

Readers might consider Watson and Crick mean-spirited for celebrating Pauling's blunder, especially since his work had been such an inspiration to them. Of course, they were really celebrating the fact that they would have more time to study DNA. Similarly, while informing Pauling about his mistake might have been the right ethical choice, Crick and Watson were clearly more interested in discovering DNA for themselves.

CHAPTER 23

Maurice Wilkins was busy when Watson visited to report Linus Pauling's blunder. Instead, Watson visited Rosalind Franklin—who asked him not to burst into her lab without knocking. He showed her Pauling's paper and pointed out the error, but she calmly noted that there still wasn't any evidence for DNA having a helical structure at all—her X-ray diffraction evidence disproved the idea. But Watson told her that she interpreted her X-ray data wrong: the distortions she saw in her images weren't evidence against helices, but rather evidence of how helices fit together into a crystal structure. Franklin started angrily walking toward Watson, who ran to the door in fear. At just that moment, Maurice Wilkins entered the doorway, looking to meet Watson. Franklin slammed the door shut, and the men went for tea.

Watson's visit to Franklin only reinforced his preconceptions about her. However, readers already know that his descriptions of her are highly unreliable. From Watson's perspective, it's understandable why Franklin's uncooperative and standoffish personality would be frustrating, especially since they could have been working together on DNA research. But from Franklin's perspective, it's easy to see why Watson would have been just as frustrating, as he barged in unannounced and started to challenge her interpretation of her own results in her own field of expertise. (Meanwhile, he was a decade younger than her and had very little experience in crystallography.)

In the hallway, Maurice Wilkins told Watson that Rosalind Franklin also nearly attacked him once. He revealed that he and his assistant were copying Franklin's X-ray diffraction images, and that Franklin discovered a new form of DNA (the "B" form). Wilkins showed Watson an image of it, and Watson was astonished: the "B" form was very simple, and it was clearly a helix. Wilkins agreed, but he explained that the real problem was where the nitrogenous bases and sugar-phosphate backbone were located. Watson explained his fear that Linus Pauling would quickly find the solution, but Wilkins wasn't convinced. Then, their conversation strayed to other topics. On the train back to Cambridge, Watson decided that he would start building a two-chain model of DNA.

Franklin's diffraction image gave Watson and Crick a definite advantage over Pauling. But it also created a major controversy, which is still ongoing many decades after Franklin's death and Crick and Watson's discovery. While sharing data is the norm in science, taking someone else's data without their permission is not. And yet Crick and Watson's theoretical innovations simply wouldn't have been possible without Franklin's data—or the years of hard work that went into producing it. Still, there's no clear answer to the questions that Crick, Watson, and Wilkins's behavior raised: what should they have done with Franklin's data? How much credit did Franklin deserve for helping discover the double helix? Did Franklin have the right to use her own data to build her own theory before anyone else? Or was taking her data justified, because she rejected the correct idea that DNA could be helical? Most importantly, how should scientists divide their time, attention, and credit between theory-building and experimentation?

CHAPTER 24

In the Cavendish Laboratory the next morning, Watson told Max Perutz and Sir Lawrence Bragg about Maurice Wilkins and Rosalind Franklin's "B" form of DNA. Watson explained that he wanted to beat Linus Pauling to the solution, and Bragg encouraged him. Watson ran downstairs and started putting in an order for new **molecular models**. Then, Crick arrived. He reported on the success of his dinner party with Watson's sister Elizabeth and the handsome French student Bertrand Fourcade. But Watson quickly turned the conversation to the "B" form. Crick was intrigued—although, while Watson favored a two-chain model, Crick suggested that two- and three-chain models were equally likely.

As Franklin's experimental evidence brought Crick and Watson closer to a solution, they finally got Bragg's permission to work on DNA. Of course, Bragg had a longstanding, friendly rivalry with Pauling—so he also wanted to reach the solution first. At last, Crick and Watson had proven that they were more likely to actually get there than to embarrass the lab. And, at last, they finally returned to a level of excitement and intensity that they hadn't reached since building their first, unsuccessful DNA model. Still, they had many questions left to answer—including basic ones, like the number of chains in the DNA molecule.

Watson and Crick kept working on their usual research for three more days, while they waited for their **molecular models**. Meanwhile, Watson also went to dinner with Elizabeth, Bertrand Fourcade, and Peter Pauling (who talked about girls, as usual).

Even if Crick and Watson were racing against the clock, there were still practical limits to their research. Socializing with their colleagues (and with women) was another component of their lives as academics.

When the first **molecular models** were ready, Watson started trying to put together a two-chain model of DNA. For the first day and a half, he put the sugar-phosphate backbone in the center and the nitrogenous bases on the outside, but he couldn't come up with a viable model. He knew that the opposite could also work: the backbone could be outside and the bases inside. But if this was true, there would be a practically infinite range of viable solutions. He started tinkering around with this form, and by the end of the week, he was making progress.

Even though Watson and Crick had better data and new insights about DNA, they couldn't deduce very much about its structure with certainty. Instead, they began modeling it through a process of trial and error. They had no guarantee that their strategy would work, and they could have always found new flaws in their model, which would have eliminated whatever limited progress they had already made.

Over the weekend, Crick and Watson went to a party. Then, they hosted Maurice Wilkins, who said he was waiting until Rosalind Franklin left to begin working with **molecular models**—but wouldn't mind if Crick and Watson started doing the same in the meantime.

Because Wilkins had worked so closely with Crick and Watson for so long, he was somewhere between an ally and a rival. Surely, Wilkins's research into DNA structure would have raised many more difficult ethical questions for Crick and Watson if they hadn't been close to a solution before he even started.

CHAPTER 25

Over the following days, Crick started to grow uneasy with how little time Watson spent in the lab. Almost every day, he played tennis in the afternoon, had drinks with French girls at the boarding house after tea, and went to the movies at night. But he also thought constantly about his DNA research. He knew that he had a possible shape for the backbone, and that it was consistent with Rosalind Franklin's experimental data. However, nobody knew that he had these data—actually, they got them because Max Perutz was part of the oversight committee assessing Maurice Wilkins and Rosalind Franklin's lab.

Crick and Watson approached their research in different but complementary ways: Crick spent his days poring over data and models in the lab, while Watson tried to stimulate his creativity by enjoying himself. Meanwhile, Watson again points out that he technically wasn't authorized to use Rosalind Franklin's data—but he avoids addressing the serious ethical questions that this raises.

When Watson got home every night, he sketched out different structures for the four nitrogenous bases. He needed to figure out how to position the bases on the inside of the structure in an irregular order, without disrupting the consistent shape of the backbones. Moreover, a recent paper had convinced him that, contrary to his previous assumptions, hydrogen bonds *did* hold the two strands together. But he needed to figure out how this was possible.

Crick and Watson knew that DNA could be structurally separated into two main parts: the sugar-phosphate backbone that holds the molecule together and the nitrogenous bases that encode genetic information by forming a specific sequence. This is why Watson needed to figure out how the molecule could accommodate an irregular order in the bases while maintaining a regular shape in the molecule overall. But since the bases were all different shapes and sizes, in theory, an irregular order of bases should have created an irregularly shaped molecule.

A week later, Watson thought up a possible solution. He remembered that adenine, thymine, guanine, and cytosine can all hydrogen bond with themselves. Therefore, perhaps the two strands of DNA could have the same sequence of nitrogenous bases, with hydrogen bonds holding them together. But the problem with this theory is that the different bases have different sizes, so the backbone wouldn't be able to have a consistent shape. Still, the idea was promising. In fact, if DNA has two identical chains, then one was likely the template for the other. This means that the DNA structure would likely hold the secret to gene replication, too. That night, lying in bed, Watson was overcome with wonder at this idea.

Watson's feeling of utter wonder and exhilaration shows why science can be so emotionally and psychologically rewarding: it's like solving a profoundly important puzzle. While Watson knew that his newest theory wasn't perfect, he also recognized that it was a major step forward. If the vertical sugar-phosphate backbones are on the outside of the DNA molecule, and the nitrogenous bases point inwards horizontally, then hydrogen bonds between the bases can hold the two strands of DNA together, like the rungs in a ladder. But if these nitrogenous bases are always identical on both sides, then every rung on the ladder will have a different shape (because so do all four of the bases). Therefore, the DNA molecule would be full of bulges and indentations.

CHAPTER 26

The next morning, Watson wrote a letter to Max Delbrück, defending his bacteria research and briefly describing the innovative new structure he developed for DNA. But a few minutes after Watson mailed the letter, the crystallographer Jerry Donohue explained that his new DNA structure was all wrong. Watson based his structure on molecular forms in the book *The Biochemistry of Nucleic Acids*, but Donohue strongly believed that the book listed incorrect forms for guanine and thymine. It put a crucial hydrogen atom in the wrong place. Donohue didn't have definitive proof, but he was one of the world's foremost experts on this topic.

Watson quickly regretted mentioning his new theory to Delbrück. He let excitement, pride, and wishful thinking get in the way of rationality and prudence—just like with his and Crick's first model of DNA. Much like Peter Pauling's letters from his father, Jerry Donohue's input on an arcane detail from a biochemistry textbook was a total coincidence, but it also made an essential difference in Crick and Watson's work. Again, this shows that they never could have succeeded if they hadn't been surrounded by the right people at the right time—and incredibly lucky.

Back at his desk, Watson quickly realized that Donohue's insight made his model impossible. Crick added that, if the two DNA strands had the same sequence, this would make the helix's angle of rotation impossibly low. Crick also noted that Watson's model couldn't explain Erwin Chargaff's finding that DNA has the same amount of adenine as thymine and guanine as cytosine. After lunch, Watson started avoiding work because he was afraid that he'd never be able to fix his model. Because the shop still hadn't sent his **molecular models** for the nitrogenous bases, he spent the afternoon making cardboard versions instead.

Crick and Watson had to discard their second model, even though it was better than their first. They could still learn from their failure. On the plus side, their second model explained how DNA molecules can hold themselves together and replicate, and Crick and Watson could keep these features in their subsequent models. But the second model failed to explain Chargaff's findings or show how DNA could have a regular molecular structure with an irregular series of bases. Therefore, Crick and Watson needed to focus their energy on those problems.

In the morning, Watson started experimenting with his cardboard models. He soon realized that adenine and thymine could be linked by a hydrogen bond, as could guanine and cytosine. Moreover, these linked pairs had exactly the same shape. Watson was ecstatic. First, these pairs explained Erwin Chargaff's findings. Second, they suggested that a two-strand DNA molecule with an irregular series of nitrogenous bases could still have a regularly-shaped backbone. In this structure, adenine and thymine would always bond together, as would guanine and cytosine. Finally, since one chain would be the other's mirror image, this structure also explained how DNA could replicate itself.

This flash of insight was the key to Crick and Watson's success. In this passage, Watson describes the double helix model of DNA that students learn about today. But his insight about adenine, thymine, guanine, and cytosine didn't just provide a viable model of DNA—meaning one that satisfied all the important theoretical requirements and fit with all the available experimental evidence. It also yielded a remarkably elegant model of DNA that clearly revealed its own function. In other words, complementary base pairs weren't just a good way for DNA to replicate and keep a regular shape with irregular bases—they were the simplest and sturdiest solution that Watson could possibly imagine. So, finding this solution didn't just crack the code of DNA—it was also a testament to the beauty of nature and the power of science.

As soon as Crick arrived at the lab, Watson explained his findings. Crick was soon convinced. Although Watson preferred not to reveal their discovery until they were sure, at lunch, Crick told everyone who would listen that they discovered "the secret of life."

While Watson claims to have reached his pivotal insight alone, he still immediately wanted Crick's input—after all, Crick had easily pointed out the problems with Watson's previous models. Convinced that they had the right answer, they struggled to contain their excitement—after all, they fully understood how consequential DNA would be for the future of biology and genetics.

CHAPTER 27

Crick and Watson knew that their discovery was incredibly important. Their next step was to build a formal 3-D model of **the double helix structure**. The next day, they explained their findings to John Kendrew and Max Perutz, then received the final **molecular model** parts from the shop and started building. They were done by dinner. Next, they had to measure the location of all the atoms in the structure. At dinner, Odile Crick asked if, given her husband's new discovery, they might be able to stay in Cambridge instead of going to Brooklyn.

After their first blunder, Crick and Watson learned their lesson: even if they could get away with bragging about their discovery in a bar, they shouldn't start informing other DNA scientists until they were entirely sure that it was right. In a way, then, their failures actually molded them into shrewder scientists. Meanwhile, Watson presents Odile Crick as completely oblivious to the gravity of her husband's discovery. In fact, her worries about living in America show how labor was divided in Oxford: men like Francis Crick got to spend all their time doing intellectual work, while women like Odile Crick take care of those men's material needs. Thus, Francis's life likely wouldn't have changed very much in Brooklyn, while Odile's would have changed completely—even though she wasn't even the one who wanted to move.

Watson and Crick spent the next few days measuring the coordinates of each atom in their model. They also showed their work to Sir Lawrence Bragg. After they finished their measurements, Watson wrote to Max Delbrück and Salvador Luria. But neither he nor Crick wanted to call Maurice Wilkins, who had just written them saying that he was about to start using **molecular models** to look for the structure of DNA.

After Crick and Watson verified their data enough to inform scientists outside their immediate circle about their discovery, they still felt guilty about facing Maurice Wilkins, because they recognized that he put more time and effort into DNA than anyone else. They clearly felt that to some extent, they may have stolen work that was rightly Wilkins's. In fact, Wilkins's experiments were the very reason Watson became interested in DNA crystallography and went to England in the first place. And as Watson noted at the beginning of the book, by English convention, Wilkins should have had the first shot at modeling DNA—he only didn't because he was waiting for Rosalind Franklin to leave his laboratory first.

CHAPTER 28

After Maurice Wilkins arrived in the Cavendish Laboratory, he spent a long time silently studying Crick and Watson's **molecular model**. Watson realized that if it weren't for Jerry Donohue's comment about the different forms of guanine and thymine, he never would have discovered **the double helix structure**. Next, Wilkins returned to London to check the model against his lab's X-ray diffraction data. To Watson's relief, Wilkins was excited, not bitter or resentful. Two days later, he called from London: based on their X-ray data, he and Rosalind Franklin strongly agreed with the double helix model. Everyone quickly made plans to publish their results.

Wilkins's response to Crick and Watson's discovery shows that he cared more about the advancement of DNA science in general than about his own personal career success. His sense of curiosity and wonder at this discovery was much stronger than his sense of pride. But Watson also recognized that this discovery was only possible because of numerous other scientists' contributions. In fact, Wilkins and Franklin even made a significant contribution to it by checking Crick and Watson's data.

Watson was especially surprised to hear that that Rosalind Franklin immediately accepted the new model, after resisting a helix structure for so long. Even more unexpectedly, when Crick and Watson visited London, Franklin began treating them with respect and sharing her data with them. Watson declares that she no longer sounded like "a misguided feminist." He and Crick even started to understand Franklin's frustration with Maurice Wilkins, who didn't recognize her talent.

Franklin's attitude and Watson's feelings about her finally started to change—at last, they treat each other more or less as equals. But readers may view this as too little, too late. Clearly, Watson didn't warm up to Franklin because his sexist ideas about women and feminism changed. Instead, he did so because Franklin finally respected and accepted his scientific work, so he no longer resented her. In fact, ironically enough, Watson could also empathize with Franklin based on his own past—most senior scientists (including Franklin) didn't recognize the significance of Crick and Watson's work for a very long time.

Crick and Watson also received two important letters about Linus Pauling. In the first, Max Delbrück reported that Pauling was still having serious trouble with his DNA models. Pauling himself wrote the second to ask about Crick and Watson's new DNA structure. Watson realized that he told Delbrück about the earlier structure, which failed—so he was relieved to see his newer one succeed. The organic chemist Alexander Todd also visited and confirmed the sugar-phosphate backbone structure. Then, Watson left Cambridge for a week-long trip to Paris.

With Wilkins and Franklin's approval, Crick and Watson were ready to spread news of their discovery to the U.S. Although Delbrück and Pauling didn't know it yet, theirs letters essentially confirmed that Crick and Watson had won the race for DNA. But Watson also sees how lucky he was: if he hadn't improved on the older, unsuccessful model that he actually presented to Delbrück in his letter, he would have had to admit that it was wrong. In other words, his discovery saved him from another round of embarrassing, public failure.

CHAPTER 29

When Max Delbrück received Watson's letter about **the double helix structure**, he started telling everyone in his lab about it. The news quickly reached Linus Pauling, who responded with "genuine thrill." In Paris, the Canadian phage biochemist Gerry Wyatt told Watson about phage DNA results that also strongly supported the double helix structure. Meanwhile, back in Cambridge, Crick put together a new **molecular model** for the "A" form of DNA.

Linus Pauling's reaction of "genuine thrill" shows that he greatly valued scientific progress in general. Like Maurice Wilkins, he was more satisfied to see DNA's mysteries solved than he was disappointed to have not been the one to solve them. (Of course, Pauling's attitude toward Crick and Watson was far more generous than Crick and Watson's attitude toward him, after his own DNA model failed.) Moreover, while the public often associates scientists with one or two great discoveries, Crick and Watson's work clearly didn't end with their great discovery about the double helix. On the contrary, their discovery created much more work for them and opened endless and exciting new paths for research.

Watson and Crick drafted their paper within a week. Rosalind Franklin and Maurice Wilkins asked them to mention a colleague who also experimented with hydrogen bonds in DNA, and Watson and Crick reluctantly agreed. Crick wanted to explain all of their work's far-reaching implications, but Watson convinced him to leave just a brief note about the DNA replication mechanism. Sir Lawrence Bragg was delighted at Crick and Watson's discovery. Not only did they beat Linus Pauling, but they also used the X-ray technique that Bragg invented decades earlier. Watson's sister Elizabeth agreed to type up the final paper, which Bragg sent to the prominent journal *Nature* on April 2, 1953.

Crick and Watson confronted two of the most important (and most difficult) parts about publishing their work: how to give credit where it's due and how to describe the consequences of their research without straying too far from the facts. The first is an ethical problem about scholars' obligations to the community that makes their work possible. Indeed, readers may feel that Crick and Watson didn't give enough credit to many of the people who made their discovery—including, most notably, Rosalind Franklin. The second problem is really about how to communicate the sense of wonder and possibility that animates their interest in science and DNA, while remaining scientific and professional. In fact, Crick and Watson's approach to this problem—noting the possible implications of their theory without waxing poetic about the meaning of life—has become by far the most famous line in their paper.

Two days later, Linus Pauling reached Cambridge. He affirmed that he thought Crick and Watson were right. That night, Linus and Peter Pauling, Francis and Odile Crick, and Watson and his sister Elizabeth all had dinner together. The next day, Watson and his sister flew to Paris to celebrate Watson's birthday and say goodbye before Elizabeth would go home and then get married in Japan. While Elizabeth was having tea with a friend, Watson stared at French girls on the street.

Linus Pauling had more to gain than anyone else by finding flaws in Crick and Watson's model—so his support for it essentially sealed the deal for them and eliminated any lingering doubts that they were right. Their dinner is also significant. Throughout the book, senior scientists nearly always dismissed, ridiculed, or otherwise looked down on Crick and Watson's work when they met or shared dinner. But Pauling dined with Crick and Watson as equals, signaling that they deserved as much respect as anyone in the scientific community. Yet the book's closing scene shows that, despite making one of the most important scientific discoveries of the 20th century, Watson remained an ordinary young man with an ordinary social and family life. Clearly, despite his coming scientific fame, he was still on the lookout for love.

EPILOGUE

Watson notes that when he published this book in 1968, almost all of the people mentioned in it were still alive and working—including Herman Kalckar, John Kendrew, Max Perutz, Sir Lawrence Bragg, Hugh Huxley, Francis Crick and Maurice Wilkins, and Peter and Linus Pauling. The only exception was Rosalind Franklin, who tragically died of cancer in 1958. Watson admits that his first impressions of Franklin were wrong, and he praises her exemplary scientific work. She eventually developed a friendly collaborative relationship with Francis Crick, and Watson regrets his conflicts with her and his blindness to the difficulties that women face in science. The book ends with a photocopy of Watson's letter describing **the double helix structure** to Max Delbrück.

Watson's epilogue, like his preface, was partially a response to the controversy that arose when he first tried to publish this book. He emphasized that his former colleagues were still alive and working for two main reasons. First, he wanted to emphasize that they had made (and were still making) important scientific contributions of their own. While they were supporting characters in Watson's story, their own stories were also worth telling. And second, Watson wanted to point out that his colleagues were all available to narrate their own version of events, in the likely case that readers, critics, or fellow scientists took issue with the way he portrayed the past in this book. While Watson recognizes that he was unfair to Rosalind Franklin in his book, his comments stop just short of an apology. Of course, he also chose not to correct his comments. His justification for this was that he wanted to present events as he first experienced them in the past. Still, readers may not agree that this is a sufficient reason to leave in sexist commentary.

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