Photo Finish: Rosalind Franklin and the great DNA race

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The structure of DNA, the molecule of life, was discovered in the early months of 1953. Nine years later, three men were jointly awarded a Nobel Prize for this achievement, which has proved to be one of the most consequential in the history of science. James Watson and Francis Crick, who worked at the Cavendish Laboratory, in Cambridge, England, came up with the famous double-helix structure. The third man honored, Maurice Wilkins, was a scientist in London; although he worked at a rival lab, he did make available to Watson and Crick some of the experimental evidence that helped them clinch their discovery. The person actually responsible for this evidence, however, was not Wilkins but an estranged colleague of his named Rosalind Franklin, who had died four years before the prize was awarded.

For a decade after her death, Rosalind Franklin remained little known beyond the world of molecular biology. Then, in 1968, Watson published "The Double Helix," his rambunctious, best-selling account of the race to solve the structure of DNA. In its pages, Rosalind Franklin becomes Rosy, a bluestocking virago who hoards her data, stubbornly misses their import, and occasionally threatens Watson and others with physical violence—but who might not be "totally uninteresting" if she "took off her glasses and did something novel with her hair."

Friends and colleagues of hers mounted a counter-offensive, which was soon joined by feminist historians of science. Why did Watson create Rosy the Witch? Out of guilt for having used her evidence, which Wilkins showed him without her knowledge. Neither Watson nor Crick ever admitted to Franklin that they had relied crucially on her research; neither so much as mentioned her in his Nobel acceptance speech. Moreover, Franklin herself had made great progress toward identifying the structure of DNA. Had she not been the rare woman laboring in a patriarchal scientific establishment that limited her opportunities and stifled her talents, the triumph might well have been hers. So her partisans have contended.

"Since Watson's book, Rosalind Franklin has become a feminist icon, the Sylvia Plath of molecular biology, the woman whose gifts were sacrificed to the greater glory of the male," Brenda Maddox writes in "Rosalind Franklin: The Dark Lady of DNA" (HarperCollins Publishers, 2002). This mythologizing, Maddox thinks, has done Rosalind's memory a disservice. One wouldn't guess from the "doomed heroine" caricature, for instance, that Rosalind enjoyed an international reputation in three different fields of research. Nor would one guess from Watson's depiction that, far from being frumpier than the average Englishwoman, she had actually brought with her to London elements of Christian Dior's New Look that she had picked up during her years in Paris. Maddox, who has previously written lives of D. H. Lawrence and Nora Joyce, tells Rosalind's story engagingly. We get a vivid picture of her scientific prowess, the complexity of her character, and the stoicism with which she pursued her research during her final months even as she was dying of ovarian cancer. Inevitably, though, it is her part in the DNA drama which commands the most interest. Did she really play an indispensable role in the great 1953 discovery, as Maddox finally joins so many others in suggesting? Was she cheated of the credit due her because she was a woman?

Rosalind Franklin was born in London in 1920 to a prominent Anglo-Jewish family. (Her great-uncle had been installed by the British as the first High Commissioner of Palestine.) The one indulgence of her "frugal rich" parents was foreign travel; they favored vigorous mountain hiking trips—an activity that became a Wordsworthian passion for Rosalind. At sixteen, she chose science as her subject, selecting the "hard" areas of physics, mathematics, and chemistry rather than the botany and biology courses usually taken by girls. She avoided the social whirl. At the age of twenty-one, after three years of study at wartime Cambridge, she confessed to a cousin that she had never been kissed and did not know how the human ovum was fertilized. In 1945, she submitted a Ph.D. thesis on how the porosity of carbon was affected by heat, a subject she mockingly described as "the holes in coal."

In fact, Rosalind's research predilections centered on something very beautiful, the idea of a crystal. To a mathematician, a crystal is a regular system of points that, if repeated indefinitely, will fill all of space. For a crystal in nature, such as table salt, these points are invisibly tiny atoms that are held in place by chemical bonds. In the early twentieth century, it was found that the wavelength of X rays is about the same as the space between atoms in crystalline matter. As X rays penetrate a crystal, they are deflected by the rows of atoms. This causes interference among them: some of the waves reinforce one another, while others cancel one another out. If a photographic plate is placed on the other side of a crystal being bombarded with X rays, a pattern of bright and dark spots eventually appears—a pattern that, in principle, would allow one to infer the molecular architecture of the crystal.

Rosalind eagerly absorbed the theory of crystallography, and so joined, as Maddox puts it, "the small band of the human race for whom infinitesimal specks of matter are as real and solid as billiard balls." Upon finishing her doctoral work, she got the offer of her dreams: a job at a crystallography lab on a quai up the river from Notre Dame. The four years that she spent in Paris, from 1947 to 1950, were evidently the happiest time of her life. Living in a garret in the Faubourg Saint-Germain, speaking almost accentless French, and working with a congenial and cultured group of scientists, she felt at home in a way she never had in England. The head of her *labo* was a dashing and brilliant Russian-born Jew named Jacques Mering, whose specialty was the study of "disordered matter"—crystals whose molecular arrangement was in some disarray. Rosalind picked up crystallographic expertise from Mering, and she also seems to have developed romantic feelings for him, even though he was already equipped with a wife and a mistress. Maddox speculates that Mering "made advances of some sort" to Rosalind, and that "she allowed herself to be tempted farther than was usual for her but eventually, incapable of a casual liaison, drew back." If so, it was probably the closest brush she ever had with carnal knowledge. As one of her fellow-*chercheurs* later put it, she was "like Queen Victoria about men."

Despite the pleasures of her life and work in Paris, Rosalind had always planned to return to London. In England, as in America, chemists and physicists were discovering a new research vista: life. The cells that make up an organism, after all, consist of atoms and molecules, which must obey the laws of physics and chemistry. It made sense, therefore, to try to bring the concepts and methods of the physical sciences to bear on biological mysteries. (After the creation of the atomic bomb, physicists found the prospect of escaping from the science of death to the science of life especially appealing.) Rosalind, though avowedly "ignorant about all things biological," applied for a position at the biophysics laboratory of King's College, London, and was accepted. Her arrival there, in 1951, marked the beginning of what Maddox calls "one of the great personal quarrels in the history of science."

The man who gave Rosalind the job in London, J. T. Randall, was something of a war hero in Britain because of his role in the development of radar. He was also happily out of step with the misogyny that prevailed in the scientific establishment at the time. Randall put women into more than a quarter of the positions in his lab and had a reputation for creating a helpful environment for them. The task he offered Rosalind was to investigate the structure of "certain biological fibres in which we are interested"—namely, DNA. This could scarcely have been a more important assignment. But the setting in which she was to carry it out filled her with gloom. King's College was dominated by clerics ("hooded crows," she called them) who trained students for the Anglican priesthood. The scientists were relegated to a cellar laboratory on the Strand, built around a bomb crater from the war. The atmosphere struck Rosalind as coarse and schoolboyish. Worse, her new colleagues were intellectually mediocre. As she wrote to a friend in Paris, "There isn't a first-class or even a good brain among them—in fact nobody with whom I particularly want to discuss anything, scientific or otherwise." The greatest indignity came when she found that she was expected to share the DNA project with the lab's deputy director, Maurice Wilkins, whom she soon decided she could not abide.

Wilkins was a New Zealand-born physicist who had worked on the Manhattan Project during the Second World War. He was unmarried and in his mid-thirties when Rosalind encountered him—tall, gauntly handsome, and attractive to women. His mild temperament, a little old-maidish perhaps, contrasted with Rosalind's brusque combativeness. She found him "middle class" and unworthy of being her collaborator. Wilkins made little gestures to win her favor, like buying her chocolates, but to no avail. When he gave a progress report on his own crystallographic research on DNA, Rosalind peremptorily ordered him to abandon X-ray work and stick to his optical studies. "Go back to your microscopes" is how he recalls her putting it.

What Wilkins described on that occasion was evidence he had obtained which suggested that DNA had the form of a helix, rather like a spiral staircase. Helices were very much in the air at that moment. Only a few months earlier, Linus Pauling had published his discovery that certain proteins had a helical form. Pauling, who was working at Caltech, in Pasadena, was the foremost chemist of his time. Since he had discovered the structure of one important kind of biological molecule, it was natural for him to start thinking about DNA. Meanwhile, in Cambridge, at the Cavendish Laboratory, a thirty-five-year-old physicist named Francis Crick was becoming friends with a twenty-three-year-old American biologist named James Watson. Watson knew genetics; Crick knew X-ray crystallography. Impressed by Pauling's achievement, and having heard from Wilkins what the King's College lab was up to, they also turned their attention to the structure of DNA.

The stage was set for a three-way competition among London, Cambridge, and Pasadena. London, however, had an enormous advantage: a jam jar containing the best sample of DNA in the world. The gooey gel could be stretched out into long, fragile strings. "It's just like snot!" Wilkins exclaimed. Rudolf Signer, a Swiss scientist who had isolated the sample from the thymus glands of calves, had generously given it to Wilkins at a scientific meeting. How Signer managed to get DNA in such a pristine form is a mystery; he never fully explained his recipe. But it soon became clear that his gel could yield beautifully crisp diffraction patterns.

Upon Rosalind's arrival at King's College, the Signer DNA was turned over to her. Using state-of-the-art equipment, she began to get superb X-ray photographs. She also found that the Signer DNA fibres could be made to assume two distinct forms: a longer "wet" form, and a more compact "dry" one. All earlier X-ray photographs of DNA had been a confusing blur of the two. But when Wilkins pointed out that her patterns, too, were consistent with a helical structure, Rosalind snapped, "How dare you interpret my data for me?" His proposal of collaboration was angrily rejected. The atmosphere in the lab became so poisonous that Randall had to intervene, setting out a formal division of labor. Rosalind got all the Signer DNA and the new X-ray cameras. Wilkins was left with the old equipment and an inferior sample of DNA. And that was more or less the end of any communication between them.

Maddox does not hesitate to assign blame for all this. "The rift was Randall's doing," she writes. In inviting Rosalind to the King's College lab, he had sent her an ambiguous letter leading her to believe that she would be in exclusive command of the DNA project; it was understandable, the author implies, that she should resent Wilkins's continued involvement. Wilkins was not the only object of her animosity in the lab, however. "She nearly terrified the living daylights out of me," one graduate student recalled. Maddox attributes Rosalind's rebarbativeness to the patriarchal atmosphere of London: "In Paris she was confident, admired, independent. Now she was a daughter again." That may be; but it is also true that, less than a year after her return to England, Rosalind found herself in sole custody of all the experimental means needed to discover the structure of DNA.

In Cambridge, Watson and Crick had none of that. They did, however, enjoy a remarkable personal affinity. "Neither had an ounce of depression in him, while Rosalind and Maurice, in their very different ways, were prey to melancholy," Maddox writes. Watson and Crick's approach to the structure of DNA was inspired by the method that Linus Pauling had used so successfully with proteins: model-building. Guided by the rules of chemistry, they would make an educated guess about how DNA was put together, and construct a model out of metal rods and wires and colored plastic balls. No need to mess around with any snotlike gel. Rosalind had nothing but scorn for this speculative approach. Even if one managed to slap together a model that satisfied the X-ray data, how could one be sure that it was the only model that would do so? How would one know, she wondered, whether it was "the solution or a solution"?

What everyone at the time did know about DNA was that it consisted of a sequence of four different bases attached to a sugar-phosphate chain. These bases were adenine, guanine, thymine, and cytosine (usually abbreviated A, G, T, and C). The precise sequence presumably encoded the genetic information. As for the over-all architecture, it seemed reasonable to start by assuming that DNA was a helix. Pauling had already shown that a helical structure could lend stability to large biological molecules, and the preliminary X-ray evidence for DNA jibed with this hypothesis. But what kind of helix? And would its structure shed light on the molecule's singular function—self-reproduction?

In late 1951, Watson went down to listen to the London team talk about what they had learned so far, and he returned to Cambridge with a slightly garbled memory of their data. A week later, he and Crick had come up with a model for DNA. It was a triple helix, with the bases facing outward, so that they could interact with proteins. They invited the King's College group up to see their handiwork. It got a withering reception. Rosalind—who, unlike Watson and Crick, was actually a chemist—pointed out that the molecule as they had constructed it would not even hold together. Maddox reports that Rosalind was "jubilant" on the train back to London: "She had not expected the model to be right. The whole approach was unprofessional." Watson and Crick tried to salvage matters by suggesting that the two groups join forces, but Rosalind wanted nothing to do with them. After this debacle, the director of the Cavendish lab, Sir Lawrence Bragg, ordered Watson and Crick to leave the investigation of DNA to King's. As a token of compliance, the pair even sent their model-making jigs down to London, where they remained idle.

Rosalind, who now had the field pretty much to herself, was intent on deducing the molecular structure of DNA directly from the spots on the X-ray pictures, without any imaginative guesswork. Such a deduction would entail endless rounds of laborious calculation. Undeterred, Rosalind plunged in. She and her assistant also continued with their X-ray photography, taking long exposures—some lasting a hundred hours—of a single fibre of DNA. Sometime in the spring of 1952, she obtained the most stunning pattern yet for the wet form: a stark, X-shaped array of black stripes radiating out from the center. It fairly shouted helix. Rosalind numbered it Photograph 51 and put it aside. She was more interested in the dry-form photos, which contained the complex detail that, with fastidious measurement, might enable her to compute the form of DNA. And this detail did not point to a helical structure. That July, in an uncharacteristic prank, she even conducted a mock funeral for the helix. She spent the next few months with her slide rule, buried in books of numerical tables.

Maddox finds her earthbound approach understandable, given what she sees as the "hostile environment" in which Rosalind found herself: "If she had felt very confident and supported, she might have been able to make outrageous leaps of imagination." Maybe, though, she sensed little urgency to do so. Watson and Crick had been banned from investigating DNA. Pauling was still finishing up his work on proteins; and, in any case, as Rosalind knew, the only DNA photographs he had were old ones in which the two forms were deceptively superimposed. As for Wilkins, next door, he was too cowed to ask Rosalind for her data, much less for some of the precious DNA sample that had originally been his.

Watson and Crick, as it happened, could also afford to be patient. They were confident that Rosalind, in rejecting the helix, had headed up a blind alley. Crick saw how she had been misled by her painstaking measurements: the supposed anti-helical features in her photographs, he realized, were actually distortions that arose in the DNA helix when it coiled up into the dry form. Watson and Crick's method was the opposite of Rosalind's: trust no datum until it has been confirmed by theory. They were determined to solve the structure of DNA with as few empirical assumptions as possible.

Besides, what real data did they have access to? Rosalind was not publishing her X-ray photographs of DNA. Watson and Crick had heard about them from Wilkins, but not even he had seen the extraordinary Photograph 51. In May of 1952, Pauling was to be the guest of honor at a Royal Society meeting on proteins in London. Had he attended, he might well have been shown Rosalind's photographs and picked up from them what he needed to solve the structure of DNA. But the trip was aborted; because of McCarthyist suspicions about Pauling's political sympathies, the United States State Department had refused to issue him a passport.

Pauling pressed ahead with his model-building all the same, relying on his unrivalled grasp of the geometry of chemical bonds. At the end of 1952, Watson and Crick were devastated by the news that Pauling had worked out a structure for DNA. They awaited his paper with trepidation, but when it arrived, on January 28, 1953, they were delighted to find that Pauling had made the same blooper they had more than a year earlier. Like their old model, his was a chemically defective three-stranded helix with the bases on the outside. Watson and Crick knew that Pauling's errors would be pointed out to him, and that, given a second crack at the DNA problem, he would probably solve it. They figured they had, at most, six weeks.

That same day, Rosalind was giving her final seminar at King's College. She had had enough of that basement full of "positively repulsive" mediocrities, and had accepted an invitation from the great crystallographer J. D. Bernal to join his lab in London, at Birkbeck College. She would leave off DNA research and apply her X-ray skills to the study of viruses. Summarizing her work at King's, she neither referred to the wet form of DNA nor showed the splendid photographs she had taken of it. Instead, she concentrated on her supposed evidence that the dry form of the molecule was not helical.

A couple of days later, Watson turned up in her lab unbidden, offering to show her Pauling's model. When she countered with her anti-helical evidence, Watson, by his own account in "The Double Helix," decided to "risk a full explosion" by implying that she was incompetent in interpreting her own X-ray pictures: "Suddenly Rosy came from behind the lab bench that separated us and began moving toward me. Fearing that in her hot anger she might strike me, I grabbed up the Pauling manuscript and hastily retreated to the open door." Watson then encountered Wilkins, who, he claimed, told him that some months earlier "she had made a similar lunge toward him." Wilkins proceeded to do something that has widely been deemed unethical: he showed Watson one of Rosalind's photographs—probably Photograph 51. "The instant I saw the picture my mouth fell open and my pulse began to race," Watson recalled. On the train back to Cambridge, he sketched from memory, in the margin of a newspaper, the pattern he had seen.

From this point on, Watson and Crick needed only one month to wrap up the matter. Bragg authorized the two to resume their model-building, with jigs to be turned out by the machine shop. Watson plumped for a helical structure with two chains. "Francis would have to agree," he later wrote. "Even though he was a physicist, he knew that important biological objects come in pairs." Then they had a couple of lucky breaks. Crick noticed a symmetry in DNA that had eluded Rosalind and her colleagues: the crystal had the same form when it was turned upside down. As he immediately realized, this meant that the two chains that made up the helix must run in opposite directions, like up and down escalators. Their second break came when an off-the-cuff remark made by a new lab mate (a former student of Pauling's, as it happened) supplied the necessary clue to how the two chains of the helix held together. As they'd begun to suspect, it was the bases that bonded. Whenever A occurred on one chain, T was invariably paired with it on the other; the two fit snugly together because of their shapes. Ditto for C and G. Therefore, one chain of the double helix was an upside-down negative of the other. When separated, each might serve as a template on which a new, complementary chain could be assembled with exactly the same information as the old. That, Watson and Crick realized, was how the molecule reproduced itself, and how nature, for the last four billion years, had counteracted the tendency of matter to become disordered. At lunchtime on February 28, 1953, Watson recounted, his partner "winged into The Eagle"—a Cambridge pub—"to tell everyone within hearing distance that we had found the secret of life." That April, the two presented their model, in a nine-hundred-word prose poem, in the scientific journal *Nature*. The elegance with which the DNA structure merged form and function seemed to guarantee its truth. "It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material," the authors demurely noted.

Rosalind was not bowled over by Watson and Crick's model. "It's very pretty, but how are they going to prove it?" was her reaction. Rosalind, Maddox writes, "had been trained, as a child . . . as an undergraduate, as a scientist, never to overstate the case, never to go beyond hard evidence." Had Rosalind been a man, the author suggests, she might have been encouraged to be more audacious. Yet a knack for guessing at an answer ahead of the evidence is one of the things that distinguish a great scientist from a good one, regardless of gender. Perhaps Rosalind was merely a very good scientist, not a great one. Or, perhaps, given a little more time, she would have discovered the structure of DNA herself. Crick has generously ventured that she was three months away, but it is doubtful that Rosalind realized it, given her decision to leave the investigation of DNA to take up the crystallographic study of viruses.

Still, as Maddox notes, "Rosalind's Photograph 51 was the pivotal moment in the discovery of the double helix." Doesn't that make her partly responsible for that discovery? Well, there are two senses of "responsible": a moral sense and a causal sense. Rosalind was not morally responsible for the discovery, because she didn't willingly share or publish her most important data and she spurned would-be collaborators, including Watson and Crick. It was Wilkins who showed Photograph 51 to Watson. Maddox absolves Wilkins of the charge that it was unethical of him to have done so, but still maintains that Wilkins's action was "unwise." It is hard to see why. The ban on Watson and Crick's working on DNA had nothing to do with gentlemanly fair play; it was an attempt to allocate scientific resources efficiently—resources that were quite scarce in postwar Britain. Besides, Rosalind had already had the photograph for nine months without interpreting it correctly—whereas Watson saw its significance at a glance. What was unwise—and a little cowardly—was Watson and Crick's unwillingness to admit to Rosalind that they had been given access to her photograph, and their failure to acknowledge her experimental work more graciously, at least during her lifetime.

Was Rosalind, then, at least causally responsible for the DNA discovery, in the sense that it would not have happened without her? It is true that Photograph 51 helped to confirm the double-helix model. As Watson wrote in the epilogue to "The Double Helix" (added to make amends for his waspish treatment of Rosalind in the book), "The x-ray work she did at King's is increasingly regarded as superb." But she had been entrusted with the best DNA sample and the most sophisticated fine-focus cameras. There is no reason to think that Wilkins, had he been given charge of these resources, would not have obtained comparably crisp X-ray photographs—or, at least, some that were good enough to yield the few basic measurements that Watson and Crick needed.

Rosalind's later scientific career was highly successful and relatively happy. She travelled extensively in the United States, lecturing on coal to "the carbon crowd" and on the crystallography of viruses to scientific audiences. She had friendly encounters with Jim Watson (who by now had become something of a celebrity, appearing in an issue of *Vogue* opposite Richard Burton). America seemed to bring out the sunny side of this sometimes dour woman. "I have completely fallen for Southern California," she wrote in one of the many letters quoted by Maddox. (Among her Fanny Trollope-like observations was that Americans "seem to make nearly all their own furniture. It is a curious result of high standards of living—*everybody* earns a lot, so nobody can afford to pay anybody else.") While Rosalind was in California, around her thirty-sixth birthday, she became aware of persistent pains in her lower abdomen. Less than two years later, she was dead of ovarian cancer. It seems likely that her constant exposure to X rays was one of the causes.

Had Rosalind lived, would she have shared the 1962 Nobel Prize awarded for the discovery of the double helix? Maddox poses this inevitable question, only to banish it to the same idle file as "What if Kennedy had not gone to Dallas?" It's unlikely that Rosalind would have been named a co-winner along with Watson, Crick, and Wilkins, for the Nobel committee's practice—later codified as a rule—is never to divide a prize among more than three people. But Wilkins's claim to the laurel was surely weaker. His main contribution to the discovery of the double helix was not his experimental work, which was minimal after Rosalind's arrival, but his role as a go-between for the London and the Cambridge labs.

Another "what if" is worth considering. What if Linus Pauling had had access to one of Rosalind's photographs? Pauling's command of stereochemistry had already enabled him to work out the helical structure of proteins single-handedly. The information he had about DNA was meagre, though, and had been gleaned from old X-ray images that were a misleading blur of its wet and dry forms. Had Pauling come to London and had a glance at Photograph 51, he would surely have deduced the correct structure as quickly as Watson and Crick did. But Pauling was a campaigner against nuclear weapons. A witness before a committee of the House of Representatives had accused him of Communist sympathies. He was kept from seeing the King's College X-ray pictures by a State Department travel ban. As it happens, Pauling did win a Nobel Prize, his second, in 1962, the same year that Watson, Crick, and Wilkins did; but his was for peace.