The chemistry laboratory at the University of Göttingen, scene of Beilstein's happiest years. Courtesy of Günther Beer, Museum der Göttinger Chemie.

Beilstein Unbound

Unraveling the *Handbuch der Organischen Chemie*

By Michael D. Gordin

Friedrich Konrad Beilstein is the most famous scientist you have never heard of. Unless, that is, you are a chemist, in which case he is the most famous scientist you know nothing about. "Beilstein"—a name constantly on the lips of every practicing organic chemist in the world—is a book, the *Handbuch der Organischen Chemie*, a reference work that contains accurate information about the properties of all known organic compounds, keyed with such information as their boiling and melting points, specific gravity, and derivatives.

But who was Beilstein? Considerably more is known about others whose names are less often on our lips—say, Humphry Davy, Robert Bunsen, Dmitrii Mendeleev, or Linus Pauling. The chemist himself ventured a brief autobiography (reproduced on page 33) that stressed pedagogy: who trained him, where he trained others, and what texts he published to that end. Let us take Beilstein at his word and home in on his pedagogical story.

Beilstein in Germany: Student, Teacher, Editor

Beilstein's paternal line hailed from Darmstadt, and his mother's line, the Rutsches, originated in Baden. His great uncle, Konrad Rutsch, was a Protestant from the small village of Dühren, which he left at age 16, settling two years later in St. Petersburg in 1810. There he opened a grocery store roughly two blocks from the Winter Palace. In 1838 Konrad died, turning his business over to his niece Katharina Margarete Rutsch and her husband, Karl Friedrich Beilstein. Our Beilstein was the first of their seven children (five boys, two girls), most of whom retained their status as German citizens. He was educated at the Protestant St. Petrischule in St. Petersburg, where he received extremely high marks, and headed abroad upon graduation at age 15.

In Germany, Beilstein traveled to most of the prestigious educational centers for the modern chemist. He finally obtained his doctoral degree at Göttingen under Friedrich Wöhler in February 1858, a few days shy of his 20th birthday. Thus armed with academic credentials, he traveled to Paris and worked in Adolphe Wurtz's laboratory. Paris resolved Beilstein on an academic career, and he assumed a laboratory assistant position in Breslau in autumn 1859, under the fearsome charge of Carl Jacob Löwig. Breslau, and particularly Löwig's dismissive attitude towards his students, were not to Beilstein's taste. In 1860 Wöhler offered Beilstein a better position as an assistant in Göttingen.

Beilstein's main duty was practical laboratory instruction, which placed heavy demands on the pedagogue's time. Nevertheless, his six years in Göttingen can be considered the most scientifically productive and socially happiest of his life. Beilstein engaged in a series of seminal studies that expanded the credibility of August Kekulé's structure theory: he demonstrated that various organic compounds previously considered isomers were in fact the same compound, by showing that their properties were identical. As Beilstein wrote to Kekulé: "My critics reproach me for having accomplished little of real significance along this line, but it was necessary to show beforehand that there is only *one* benzoic acid, that benzyl chloride and chlorotoluene are different, and so forth, before these could bring to your theory that range and that significance which it had from the beginning." This research

Continued *on page 32*

Friedrich Konrad Beilstein as a young man. Courtesy of the Edgar Fahs Smith Memorial Collection, University of Pennsylvania Library.

The chemistry group at the University of Göttingen in 1863. In the top row Hans Hübner is second from the left, and Friedrich Wöhler and Beilstein are second and first from the right. Courtesy of Günther Beer, Museum der Göttinger Chemie.

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Rudolph Fittig in 1891. Courtesy of the Edgar Fahs Smith Memorial Collection, University of Pennsylvania Library.

Alexander Mikhailovich Butlerov (taken after 1850). Courtesy of the Edgar Fahs Smith Memorial Collection, University of Pennsylvania Library.

established Beilstein's reputation as a gifted organic chemist.

Beilstein's magnetic personality soon made him the center of a trio that included his fellow assistants Rudolph Fittig, an inseparable colleague (at one point they shared an apartment), and Hans Hübner. Fittig noted Beilstein's pedagogical gifts in his diary:

> He also stands before the laboratory students in a proper but good relation, he tells them jokes and anecdotes . . . and allows the difference between teacher and student to vanish completely. The students like this, as well as his joviality; his sharp humor makes him their darling. I am in this respect entirely different, and I will happily admit that I am abrupt, that I am too much a teacher, too schoolmasterly.

Beilstein's teaching style, however, was site specific. Away from Göttingen, it would become harder to maintain.

The Göttingen trio also had outlets outside the classroom. In 1865 they assumed editorship of the *Zeitschrift für Chemie*, founded in 1858 by August Kekulé and subsequently brought almost to ruin by Emil Erlenmeyer's demagogic editing practices. The new editors turned the *Zeitschrift* around, and the experience had an important impact on Beilstein. First, editorship involved correlating and processing diverse chemical information; moreover, the *Zeitschrift* functioned for roughly a decade as the only regular publication outlet for Russian chemists, facilitating the constitution of a Russo-German chemical community. Yet the happily advancing juggernaut of the *Zeitschrift* ground to a complete halt in 1871, when it faced staggering competition from the newly established organ of the German Chemical Society, the *Berichte der Deutschen Chemischen Gesellschaft*, founded in 1868. An added problem was an increasingly nationalistic attitude towards publishing, especially evident among the Russians —a fact Beilstein lamented on several occasions. He complained to Erlenmeyer in April 1871: "What is to become of us, when each city produces its own journal, where one must seek out one's bit of chemistry under dust, garbage, and mouse droppings." The knowledge produced by European chemists needed to be centralized and systematized, or it would be lost.

Beilstein's prowess made him a pedagogue in high demand. In April 1865 St. Petersburg University attempted to hire him, and Wöhler heavily lobbied ministers in Hannover not to let such a prize teacher go. Göttingen offered to make Beilstein an extraordinary professor at the ripe young age of 27 and threw in a sizable salary to boot—which Beilstein accepted after failing to wheedle similar blandishments from Petersburg. He couched his acceptance in pedagogical terms:

> No place has offered more and better opportunity than here in Göttingen. . . . Nowhere have I found such a pure scientific sense as here and nowhere are the students as industrious as here. I put specifically a great deal of weight on the last point. We chemists achieve very little ourselves, and only what we achieve through our students is actually valuable.

At this point no one actually believed Beilstein would abandon his alma mater, but that assumption could not have been further off the mark.

Back to Russia: The St. Petersburg Technological Institute

In 1864 Beilstein had joked in a letter to Kekulé:

> You won't believe how much you have risen in value here [since you left Germany for Belgium]. . . . What a big shot you will be, if they draw you back to Germany. I constantly wish to become a professor of chemistry in Peking or in the Sahara desert. Then I should make it difficult for [August] Hofmann to compete with me!

Beilstein would soon get his wish: in 1866, a year after he turned down a better offer, he took a position at the less prestigious Technological Institute in St. Petersburg. Beilstein's father had died somewhat suddenly at the age of 56 in April 1865, and his family needed him. In June 1867 he even gave up his German citizenship and became a subject of the tsar.

The Technological Institute was far from ideal. Founded in the late 1820s to train civilian engineers, it featured high teaching loads and apathetic students. Unlike St. Petersburg University, which was on the Neva near the Academy of Sciences, it was located south of the city center—too marginal for daily academic interaction. Furthermore, the university, which was originally focused by statute on the humanities, was experiencing a renaissance of natural scientific work after Alexander II promulgated a new statute in 1863. This intellectual shift explains in part why Mendeleev, who held posts at both institutions from 1867 to 1871, gradually moved his base of operations from the institute to the university. In essence Beilstein was hired to teach analytic and organic chemistry in an institution that had long been neglected. Hardly a second Göttingen.

We get an excellent sense of the frustrations of Beilstein's initial position at the institute in a letter he wrote to the Russian chemist Alexander M. Butlerov (then at Kazan) in November 1866. One major frustration was Mendeleev's neglect:

> Perhaps the tidings have not yet reached you in the Far East that I have now decided to move to Petersburg. I

am Mendeleev's successor at the *Technological Institute*. . . . That is no small affair, when I tell you that my predecessor—who, as you know, is not really a practical chemist—never bothered with the work of *Praktikanten* and went at most for a few minutes into the laboratory every 1/4 of the year. He was in such a rush to get Chancel and Gerhardt [a textbook—the *Précis d'analyse chimique* by Gustav Chancel and Charles Gerhardt] translated, without bothering to consider progress in analytic chemistry in the least. This book was shoved into the hands of each *Praktikant*, and then he was discharged with a blessing.

The teaching loads were also high:

How hard it is for me to introduce discipline and order will be clear to you immediately when I add that in one crowded room there are presently—175—yes, yes—175 men working! [as opposed to 80–85 at Göttingen]. . . . What kind of nonsense there is here under these conditions! I had to give up being an academic [*Gelehrter*] and am a schoolmaster [*Schulmeister*] in the harshest meaning of the word.

Beilstein perforce abandoned his collegial Göttingen teaching style and organized his laboratory "militarisch," modeling it on Löwig's Breslau laboratory, which he had hated while there.

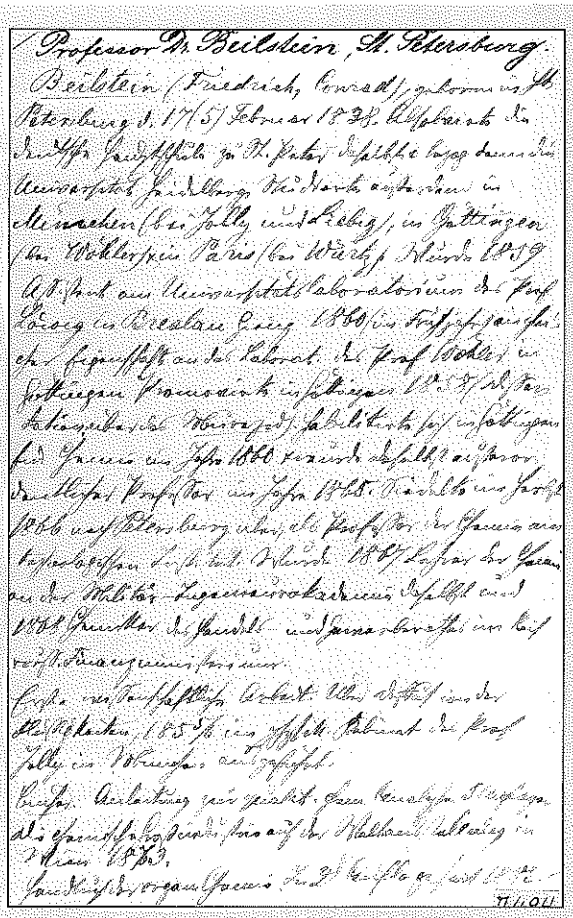
How painfully I feel this biting contrast I don't need to tell you. Although I live here in the circle of my family, I still feel the greatest homesickness for my old laboratory and my old students.

Because there was no proper textbook, Beilstein wrote his own, the *Anleitung zur qualitätiven Analyse* (Instructions for qualitative analysis), published in the late 1860s. This slim volume attempted to integrate recent innovations in analytic chemistry in a format useful for the unskilled student. It was organized as a set of instructions. The first 20 pages or so walk the student through such basic procedures as titration and heating so as to standardize techniques and basic reagents: what happens when you carbonize a substance, you moisten it, you put it to a flame, you dissolve it, and so on. The remaining 30 pages explicitly show what the student is to do when presented with an unknown substance. You first take part of the substance and add water. If it dissolves, then move to step 5; if it does not, try sulfuric acid, then move to step 7, and so on. In this fashion, the student should eventually be able to identify the substance qualitatively.

The book's absence of a formal theoretical framework made it uniquely adaptable to different countries and across major theoretical and experimental divides. Published simultaneously in Russian and German, the *Anleitung* consequently went through six editions and was translated into Dutch, English, and French.

Mendeleev as Beilstein's Bête Noire

Meanwhile, Beilstein became a visible member of the St. Petersburg chemical community. He was awarded the Lomonosov Prize of the Academy of Sciences in 1876, served as consultant for the Ministry of Finances on patent questions from 1867 on, and was president of the chemical section of the Russian Technical Society. He nonetheless felt scientifically isolated in Petersburg. A big part of the problem was Mendeleev. While in Göttingen, Beilstein could paper over their



Beilstein's resume, sent in a letter to Georg Krause. Photo courtesy of the Deutsches Museum, Munich. Transcribed and translated it reads:

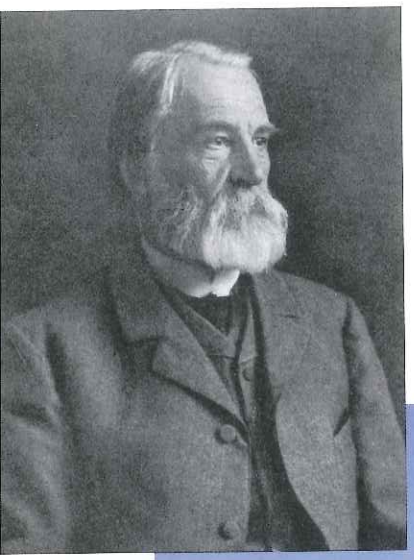
Beilstein (Friedrich, Conrad) born in St. Petersburg on 17 (5) February 1838. Completed the German high school in St. Petersburg & then moved to the University of Heidelberg. Studied besides that in Munich (with Jolly and Liebig), in Göttingen (with Wöhler) & in Paris (with Wurtz). Became in 1859 an assistant in Prof. Löwig's university laboratory in Breslau. Went in 1860 (early in the year) in the same capacity to the laborat. of Prof. Wöhler in Göttingen. Received doctorate in Göttingen in 1858 (dissertation: on murexide). Habilitated in Göttingen in chemistry in 1860 and became an extraordinary professor there in 1865. Moved in autumn to Petersburg as professor of chemistry at the Technological Institute. Became in 1867 a teacher of chemistry at the Military-Engineering Academy there and in 1868 a chemist of the Department of Trade and Manufactures in the Imperial Russian Ministry of Finances.

First scientific work: On the Diffusion of Liquids, conducted in 1855/6 in the physical cabinet of Prof. Jolly in Munich.

Books: Introduction to Qualitative Chemical Analysis, 5 editions,

Chemical Great-Industry at the World Exposition in Vienna 1873,

Handbook of Organ. Chemistry. In 2 editions as of 1885.



Beilstein in his later life. Courtesy of the Edgar Fahs Smith Memorial Collection, University of Pennsylvania Library.

mutual dislike. Right before his move Beilstein wrote Mendeleev to thank him for "all of your kindness [in] naming me your successor at the Institute." He also warned that "I will at first often make you sick of me. Moving to a new circle of activity, I will be obliged to often ask for your advice and help." But when Beilstein saw the consequences of Mendeleev's neglect at the institute, any goodwill dissipated.

Yet ignoring Mendeleev was difficult, and it became utterly impossible on 11 November 1880, when Mendeleev was denied the chair in technology at the Academy of Sciences, by a single vote. Butlerov, who had joined St. Petersburg University in 1868, had been trying to get him a seat for years. This public rejection sparked a massive outcry from Russian chemists. Nikolai Menshutkin, secretary of the Russian Physico-Chemical Society (formed in 1878 when the societies of physics and chemistry combined), asked colleagues to sign a protest, which he planned to publish in a local newspaper. On the grounds that a newspaper was an improper forum, Beilstein—the only chemist to do so—refused to sign, arguing that the society should instead honor Mendeleev at its next meeting. Even though he was overtly supportive of Mendeleev's candidacy, it was presumed that he failed to sign was because he was "German," and thus an affiliate of the supposed "German party" that was widely (and erroneously) believed to have orchestrated Mendeleev's rejection. In the midst of a broad newspaper campaign in support of Mendeleev, only one substantial article—published in German—attacked Mendeleev's qualifications. Many attributed the anonymous article to Beilstein.

The home of the Russian Academy of Sciences until 1949, this building now houses the Peter the Great Museum of Anthropology and Ethnography (Kunstkamera). Beilstein, though a member of the academy, felt scientifically isolated in Russia. Courtesy of Peter Y. Sobolev (www.enlight.ru/camera/index_e.htm).

Injury was added to insult when in 1882 the Academy of Sciences awarded Beilstein himself the very same chair, citing his contributions to the chemistry of the oil industry. Anticipating nationalist objections, the nominators declared: "We also remind you, that F. F. Beilstein is a Russian subject, a native of St. Petersburg, where he received his education, and that he commands the Russian language fully." Butlerov, as chemistry academician, now decided to blackball Beilstein at the meeting of the General Assembly of the Academy on 5 March 1882. Of the 27 academicians present, Beilstein received 17 votes, one shy of the necessary two-thirds majority. He would not receive his chair in technology until after Butlerov's death in 1886.

After 1880, Beilstein's isolation from the mainstream of Petersburg chemistry was almost complete: Mendeleev's growing status after his rejection made the Russian capital uniquely inhospitable for the displaced Göttingener. Among all Petersburg chemists of distinction, and as a founding member of the Russian Chemical Society to boot, Beilstein was unique in not being recognized by the society in any substantial administrative or honorary capacity. In 1903, under the new charter of the academy, Beilstein even lost an election to Aleksandr Zaitsev, a Kazan chemist who never attended a single meeting. Two-time president Mendeleev, on the other hand, was elected honorary president for life in the 1890s. Beilstein got the message.

Beilstein Bound: The *Handbuch*

The *Handbuch* is not thought of as a Russian text. After both world wars, for example, it was held up by German chemists as a testament to the good in German culture: Beilstein's systematization atoned for other sins. Yet in an often-quoted letter Beilstein declared: "Truly, I could only have written my *Handbuch* in Russia, and thus I have deferred calls back to Germany. At a Russian polytechnicum professors don't have to be scientifically active, because the students don't give any reason for it, but in Germany they would have looked at me disapprovingly."

Beilstein did not plan from the first to write a comprehensive reference work. Ever since Göttingen, he had been gathering material on organic compounds for teaching purposes and checking its accuracy. Only after he realized the need for an updated organic textbook in Russia did he begin to organize that material, originally for a textbook. He wrote Erlenmeyer on 22 February 1878:

> I have now earnestly gone about carrying out a plan that I have had in mind for a long time: I am actually writing an organic chemistry. Now I am in a lot of trouble. As I have all the material *completely gathered*

before me, so I hope that I can be done with the writing in about 2 years. Now I am already in the 2nd year of work & have only gotten to glycerin.

Two impulses finally drove him away from the textbook model: a self-imposed stricture "to monitor *all citations* myself" and a desire for completeness. The result:

> What I have written so far is actually more a *catalog* of organic chemistry rather than a textbook. . . . For the purpose of looking things up it is entirely excellent. . . . But with *reading* it is something else. The story comes out too dry. . . . Time is looming upon me, however: if I want to make everything also nice and easy to digest, I will be done in 5–6 years & that is too much for me. I don't have that much of my life to spend.

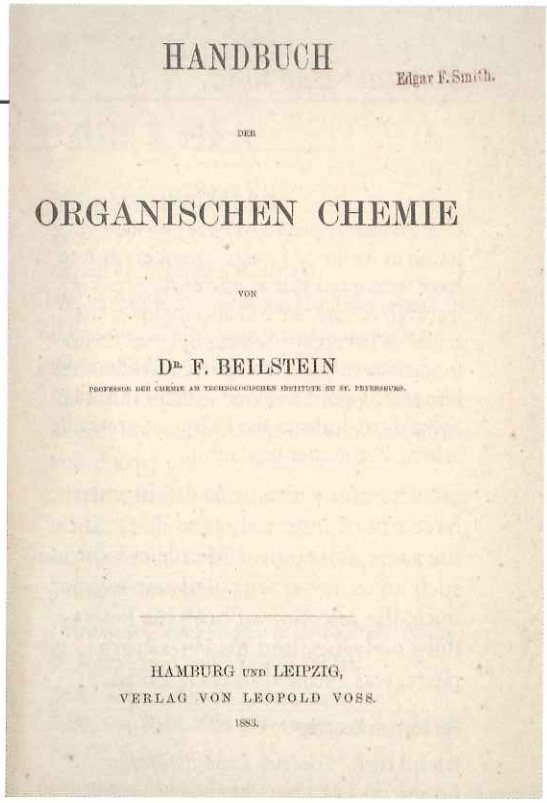
Excerpts from a speech on this 33-year effort, given to the Russian Physico-Chemical Society in 1893, convey his obsession with completeness:

> I began to read Liebig's *Annalen* correctly [only] from its 101st volume. Then I had to reread all 100 volumes. . . . Then I had to look through the entire *Jahresberichte der Chemie* in order to convince myself that nothing had been missed. . . . On the appearance of each new guide to chemistry I compared its content with my notes, and in the event of a disagreement—which happened rather often—I had to check with the original articles. . . . I had to rework the factual part, but when this was done, organic chemistry had again moved so far forward that it was necessary to redo everything over again.

This process of constant revision forced him to order the material by empirical formula alone. (The "Beilstein System," the organizing principle behind today's *Handbuch*, was instituted only in 1909.)

To create the demand for his information among chemists less conversant with structure theory than today's, Beilstein distilled into a small introduction basic theoretical principles derived from textbooks by several eminent chemists, among them Erlenmeyer, Gerhardt, Kekulé, Leopold Gmelin, and Hermann Kolbe. There he dated the history of organic chemistry from Wöhler's synthesis of urea in 1828, to show that there are chemical (as opposed to vitalist) reasons to treat organic chemistry separately. Beilstein then provided a framework within which to interpret the data in his compilation, beginning with quantitative organic analysis—determining the exact composition of organic molecules—before moving on to how their structure might influence their properties. His system was still incomplete: "As we look over the system of organic chemistry as it currently appears, we still note many holes." But this was the incentive he offered to potential users of the *Handbuch*: ground yourself in basic principles, and then you can develop the science of organic chemistry in defined directions, filling in those holes.

Beilstein published his *Handbuch* in 1881–1883 in two volumes comprising 2,200 pages and 15,000 organic compounds. The second edition grew to three volumes, and the third to four. All editions were edited by Beilstein alone or, in the case of the third, with only supplementary assistance. (By 1981, on the 100th anniversary of the *Handbuch*, the staff of the Beilstein Institute in Frankfurt stood at 160. Since 1981 "Beilstein" has been published exclusively in English, as is today's online version, and both staff and compounds covered have continued to grow exponentially.)


HANDBUCH

Edgar F. Smith.

DER

ORGANISCHEN CHEMIE

VON

D^R. F. BEILSTEIN

PROFESSOR DER CHEMIE AM TECHNOLOGISCHEN INSTITUTE ZU ST. PETERSBURG.

HAMBURG UND LEIPZIG,
VERLAG VON LEOPOLD VOSS.
1883.

Title page of the first edition of "Beilstein," volume 1. Courtesy of the Edgar Fahs Smith Memorial Collection, University of Pennsylvania Library

Despite the role his Russian situation played in the creation of the *Handbuch*, in revising it for a second edition, Beilstein turned his back on the Russians who had spurned him. He wanted it to continue as a cooperative venture, and so he petitioned the German Chemical Society in Berlin, snubbing his local peers entirely in favor of an "international" (read "German") community. This was quite a transformation for the chemist who since the 1860s had been a booster for Russian science. The German Chemical Society eventually adopted the *Handbuch* in 1896, and after the third edition's appearance and Beilstein's death in 1906, it moved there entirely.

Praise for the text was, however, international. Richard Meyer wrote to Erlenmeyer in 1882: "I use Beilstein's book daily; it became immediately indispensable; but there is a mass of errors in it! One has to go to the original articles every time; but what is good is that you can find them quickly through the book." Even the normally gruff and nationalistic V. V. Markovnikov was enthusiastic about "Beilstein's wonderful reference book," and P. P. Alekseev in Kiev commented: "I am now studying Beilstein and Kekulé. Beilstein's book is really a capital production." Perhaps the most personally satisfying review was the letter sent by Henry E. Armstrong, president of the Chemical Society of London, to congratulate the Russian Chemical Society on its 25th anniversary on 6 November 1893. In a statement addressed to Mendeleev, he wrote:

Book Reviews

Our Society is proud to have enrolled your name in its list of foreign members and to have welcomed you as one of its Faraday lecture[r]s; and the roll also includes the name of Beilstein—which, however, is no longer the mere name of an individual but a household word and one which cannot be mentioned without the feeling of gratitude arising in the chemists' mind.

The ever-sarcastic Beilstein must have smiled internally from his seat on the same dais to hear Mendeleev intone such an endorsement. Beilstein's *Handbuch*, the rejection of both his Petersburg pedagogy and his Petersburg peers, was extolled in their midst.

For Further Reading

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Michael D. Gordin is an assistant professor in the Department of History at Princeton University, where he teaches history of science and history of Imperial Russia. He received his doctorate from Harvard University, where he is a member of the Society of Fellows. His book, *A Well-Ordered Thing: Dmitrii Mendeleev and the Shadow of the Periodic Table*, is due out from Basic Books in April 2004.

A longer version of this article was written for "Training Scientists, Crafting Science," a conference organized in 2002 by David Kaiser of the Program in Science, Technology, and Society at MIT. The conference was supported by funding from the Spencer Foundation, with additional support from the NSF and from the Provost's Fund at MIT.

History Rewritten: A Reputation Redeemed

Brenda Maddox. *Rosalind Franklin: The Dark Lady of DNA*. New York: Harper Collins, 2002. 400 pp. $29.95.

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Anne Sayre. *Rosalind Franklin and DNA*. New York: W. W. Norton & Company, 2000. Originally published 1975. 240 pp. $13.95.

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Within the span of a few years two epochal scientific revelations changed our understanding and the future of our world and its life. These momentous scientific discoveries, fission (1939) and the structure of DNA (1953), had common features. For some time after the first unveiling publications, even experts had only limited vision of how much human destiny would be transformed. In both instances, science at the time unfairly failed to acknowledge primary contributions by heroic women—Lise Meitner and Rosalind Franklin—brilliant experimentalists with middle-class Jewish backgrounds who worked with severe cultural obstacles in their path. Nobel Prizes were deservedly awarded for both discoveries; but the recipients (Otto Hahn in 1944 and Francis Crick, James Watson, and Maurice Wilkins in 1962) have been called on to answer troubling questions about disregarded colleagues.

As we celebrate the first 50 years of the elucidation of DNA's structure, it is appropriate to refocus on all the fascinating issues: not only on the essence of the science, but on rivalries in research; on the benefits of communication between scientists as they carry out research; on the interests of research-funding agencies; on the attitudes towards women in science; and on how directors guide laboratory atmosphere and accord freedom of research to deserving scientists. In addition, one must admit that progress in science is made in tiny steps and missteps; it is often achieved by teams rather than individuals, so that even the best deserved awards of high-profile Nobel Prizes often distort the public view of true science.

All these issues are addressed extensively in two biographies of Rosalind E. Franklin (1921–1958), who died tragically of cancer four years before the Nobel Prizes (which are never given posthumously) were awarded for DNA. Franklin worked on DNA for only two years (1950–1953) at King's College (University of London), where she had atrocious personal relations with Wilkins. Following the famous *Nature* article on DNA by Watson and Crick (who worked at Cambridge University, under Lawrence Bragg), Franklin marveled at their model-illustrated, correct DNA structure, wondering only on what evidence it was based. Unknown to her, it was based partly on her own X-ray diffraction picture. Some months earlier Franklin had decided to give up bitter struggles at King's and join J. D. Bernal's laboratory at Birkbeck College (also University of London); J. T. Randall, the head of King's laboratory, had elicited the promise that she would no longer "think" about DNA. (She later moved to Max Perutz's molecular biology unit at the Cambridge Cavendish Laboratory.)

In 1968, 10 years after Franklin's death, Watson published *The Double Helix*, his widely read account of the story behind his Nobel Prize–winning work. The book fascinated the public with its vivid and humanizing description of great scientific research. However, Sayre, Franklin's close personal