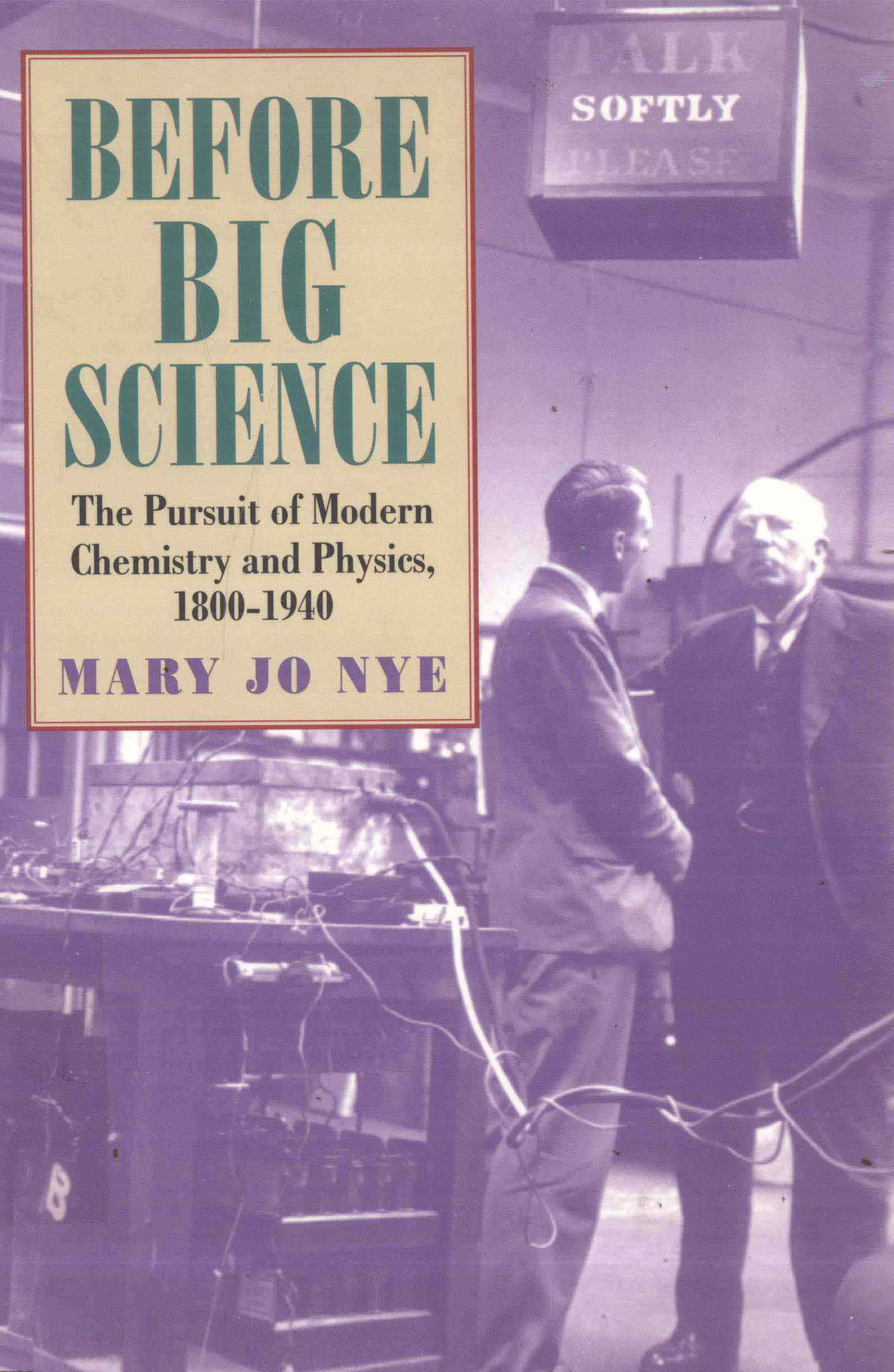
BEFORE BIG SCIENCE

The Pursuit of Modern Chemistry and Physics, 1800-1940

MARY JO NYE



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The Pursuit of Modern Chemistry and Physics 1800–1940

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Foreword

Twayne's History of Science and Society series is designed to offer students as well as educated lay readers a comprehensive survey of Western science from ancient Greece to the present. Specialists, for their part, will find here accounts of the latest research along with the distinctive outlook of experts on their respective topics. The series comprises an interlocking whole that examines the totality of western scientific experience within its broader social and cultural context. While each volume will present a concise study of the nature and scope of the scientific enterprise during a particular period, several volumes will often be grouped together to treat related periods and to create a unifying narrative line. In this way the series hopes to avoid the limitations inherent in surveys that adhere to rigid periodization and strict boundaries between disciplines.

Mary Jo Nye's *Before Big Science* launches the series with a forceful account of the maturation of the fields of physics and chemistry during the nineteenth and first half of the twentieth centuries, a period that witnessed a spate of conceptual and experimental discoveries that transformed our understanding of the natural world. It was also during this period that physics and chemistry were reshuffled and their spheres of activity reconstituted. Concomitant with this transformation of the field was the resurgence of the universities as the main sites of scientific activity. Major research facilities were established there on an unprecedented scale and the concept of the teaching laboratory was introduced. Nye describes the rapid process of professionalization that accompanied these institutional changes and effectively put an end to the ideal of the "gentleman" practitioner that had reigned during the early modern period. It was also this period that witnessed improved experimental techniques, higher levels of precision, and near universal consensus over standardization, all of which offered scientists a greater scope for investigation. Another by-product of the enormous growth of the scientific community was an exponential increase in cost, which in turn forced government to underwrite a growing share of the expenditure. Finally, the period saw the internationalization of scientific activity and emergence of the United States, in particular, as a leading force.

Writing with authority and verve, Nye provides a cogent introduction to these and other aspects of the growth of modern physics and chemistry, one that will prove indispensable for anyone interested in understanding the rise of "Big Science."

Mordechai Feingold

Preface and Acknowledgments

In writing this history, I have had very much in mind the undergraduates and beginning graduate students whom I taught for twenty-five years in survey courses in the history of science at the University of Oklahoma. Their interests and their observations have informed this history. I also have had in mind my daughter, who was a liberal-arts college undergraduate when I began this book, as well as friends and family who are general readers. I hope that this book will be interesting and informative for science students and for scientists who enjoy reading about the histories of their fields.

In writing this volume, I have depended on general histories of science from antiquity to the present, histories of physics and histories of chemistry, biographical studies, institutional histories, and monographs written by historians, philosophers, sociologists, and scientists. I have drawn from articles and books written by the historical figures whose stories are recounted here. I have incorporated ideas and arguments that I have used in lectures over the course of many years, as well as some of the work of my students, including the dissertations of my students Jun Fudano, Yasu Furukawa, and Michael N. Keas.

Because this book does not contain the great number of footnotes customary in my usual published work, I have not been able to acknowledge or cite every author to whom credit is due. I ask the reader to take seriously the origins of this book in the sources cited in the bibliographical essay.

For their specific criticisms and suggestions, and for the help or inspiration they offered in various ways, I wish to thank my former students Kuangtai-Hsu, Mark A. Eddy, and Lynne A. Williams; my present student, J. Christopher Jolly; my daughter, Lesley N. Nye; and my friends and colleagues Diana K. Barkan, Jed Z. Buchwald, Joseph S. Fruton, Frederic L. Holmes, Daniel J. Kevles, Alan J. Rocke, and Niall Caldwell and Liba Taub. Mordechai Feingold enlisted me to write this book. I am grateful for the gentle pressure that he and Lesley Polliner put on me to complete it, as well as for the skillful copyediting by James Waller and the production and editorial oversight by Andrew Libby and Margaret Dornfeld. My greatest debt, as always, is owed to Robert A. Nye, for critical reading, insightful advice, and necessary encouragement.

For courteous assistance with photographs and permissions to publish, I gratefully acknowledge the Edgar Fahs Smith Collection at the University of Pennsylvania; Cambridge University Press; MIT Press; University of Wisconsin Press; the Royal Society of Chemistry; Godfrey Argent Photography Ltd.; the National Portrait Gallery, London; the Royal Society, London; the Manchester Literary and Philosophical Society; the History of Science Collections, University of Oklahoma Libraries; and the Special Collections (Ava Helen and Linus Pauling Papers) at Oregon State University, as well as the late Francis Perrin, Mme. Colette Grignard, and Dr. Keith U. Ingold.

Support from the Thomas Hart and Mary Jones Horning Endowment at Oregon State University and a by-fellowship at Churchill College at the University of Cambridge enabled me to complete this book. It was begun with support from the George Lynn Cross Professors' research fund at the University of Oklahoma, for which I also am grateful.

Introduction: Modern Science and Big Science

There is much talk in the late twentieth century about the giant scale of things: big government, big business, big science. In 1961, Alvin Weinberg, the director of the Oak Ridge National Laboratory in eastern Tennessee, wrote an influential commentary in *Science*, the weekly publication of the American Association for the Advancement of Science, on the state of high-energy physics in the United States.

Coining the phrase "Big Science," which he wrote with initial capitals, Weinberg expressed the view that giant-scale science was a stage in the development of science. The sociologist Derek J. de Solla Price had already plotted an exponential growth curve in 1956 showing that the sheer number of scientists and scientific papers doubled in size about every fifteen years after the seventeenth century, although Price inferred that the curve was beginning to level off in the late 1950s.

The 1960s period of big science was not, in Weinberg's opinion, the ideal outcome for the history of the sciences. In particular, Weinberg judged that the large sums of money spent on contemporary high-energy physics research were of fairly low value in contributing to the general human good. In his *Science* essay, Weinberg recalled for his readers the building of the ancient Egyptian pyramids and the medieval European cathedrals, enterprises that in their own times commanded exorbitant efforts from engineers, artists, laborers, and governments. He worried, "We must not allow ourselves, by shortsighted seeking after fragile monuments of Big Science, to be diverted from our real purpose, which is the enriching and broadening of human life."[1]

Historian Daniel J. Kevles noted in his history of the American physics community that Weinberg practiced what he preached. His own management of the Oak Ridge facility was one that directed some of the national laboratory's research effort to such socially useful concerns as cheap energy sources, desalination, and environmental problems.

Of course big science was not entirely new. To be sure, the coordination of hundreds and even thousands of individuals into group efforts across industry, government, military services, and the universities reached a new scale of personnel and funding levels as a consequence of World War II. Highly visible national and multinational particle accelerators, rockets, and space vehicles resulted after the war, as well as huge research and development programs in chemical products including synthetic materials and pharmaceuticals.

Yet already before 1940, Ernest Lawrence's cyclotron program at the University of California at Berkeley operated on the basis of an array of funding sources, with 22 percent of its capital and operating budget from the federal government, along with 40 percent from the state of California and 38 percent from private philanthropic foundations. By the 1930s scientists were complaining that administrative and committee work was taking too much time and that senior scientists had no time to do research. As early as 1900 some university professors and townspeople were complaining that some parts of universities were beginning to look like factories, as huge laboratory buildings were equipped with electrical generators, enormous magnets, vacuum pumps, chemicals, and heavy machinery.

The bigness of Big Science, as well as its undergirding theoretical and organizational structures, had clear origins in its recent history. Modern science was well established before the outbreak of World War II, and there emerged many important continuities, as well as significant disjunctions, between the history of chemistry and physics before and after the war.

This book studies the individuals, institutions, and ideas that turned the late eighteenth-century traditions of natural philosophy, natural history, and chemical philosophy into the twentieth-century disciplines of chemistry and physics that are familiar to contemporary students and readers of science.

Aspects of what we call chemistry and physics originally were taught in medieval and Renaissance universities as part of the curriculum in medicine, pharmacy, philosophy, astronomy, and mathematics. During the early decades of the 1800s the subject matter of physics and chemistry was found in lecture courses in many universities throughout Europe. Only in the mid-nineteenth century, however, did the words *chemistry* and *physics* acquire well-defined disciplinary meanings that are very much like their counterparts in the twentieth century.

Although early nineteenth-century chemistry continued to be associated with the traditions of natural history (botany, zoology, geology, mineralogy) and natural philosophy (mathematical and experimental physics, also known as mechanical philosophy), by mid-century chemistry and physics were coming into their own as "physical sciences" distinct from the moral and biological sciences.

In the first decades of the 1800s, chemists' principal goals lay in isolating and describing elementary substances and their properties, determining the elements' proportions in natural and synthesized substances, and identifying typical combinations of elements that function as chemically active radicals or groups. Chemists toyed with the idea that the origin of chemical force is electrical or gravitational in nature, but they did not overly concern themselves with the nature of chemical force or with possible mechanisms of combination. Rather, they laid emphasis on classifying simple and complex substances and in working out the kinds of relationships that resulted, in the late 1860s, in the periodic table of the elements devised by Dmitry Mendeleyev.

In contrast, physicists studied mechanics, optics, and acoustics, employing first geometry and then the analytic methods of integral and differential calculus in their treatments of these subjects. By the middle decades of the nineteenth century physicists were adding to their domain some experimental fields—especially heat and electricity—that they had previously shared with chemists but that chemists by and large now conceded to them. This concession on the part of chemists was largely due to the rapid growth of what came to be called "organic chemistry," which encompassed pharmacy, animal chemistry, agricultural chemistry, the chemistry of dyes, and the industrial chemistry of organic synthesis.

Organic chemistry developed a program of study, a language of discourse, and a system of explanation that was foreign to the practitioners of an earlier general chemistry, which had shared with natural philosophers and physicists a concern for corpuscular points, Newtonian forces, and subtle fluids. Further, as natural philosophy and physics became more and more mathematical, chemical philosophy and chemistry demonstrated very little need of mathematics beyond the simplest calculations.

The chemical laboratory became a vehicle for the teaching and training of a fairly large number of students. The laboratory was a different kind of scientific institution from the philosopher's lecture theater (where he gave public demonstrations) or the academic chemist's private rooms (for experimentation and testing). The development of the teaching laboratory gradually changed the character of natural philosophy, or physics, after the mid-nineteenth century, even as it had first transformed chemical philosophy. Not just experimentation but *precise* measurement and quantification using standardized and finely tuned (if not necessarily finely crafted) instruments, were to become rigorous requisites of physics as well as chemistry.

By the end of the nineteenth century, many physical and chemical laboratories looked like factories and were turning out data in a mechanical fashion. University science faculties required separate buildings, and the split between the "humanities" and the "sciences" became a division in physical as well as epistemological space. As noted earlier, by 1940, university-associated laboratories such as Ernest O. Lawrence's laboratory at the University of California at Berkeley were practically indistinguishable from factories or industrial laboratories to the casual observer.

Today's forms of scientific education and research evolved out of the expansion and reform of universities in the nineteenth century, which created not only the laboratory but also the seminar, the colloquium, the research institute, and schools of applied and engineering science independent from the military and technical schools of the eighteenth-century state. Increasing specialization within the teaching of the sciences dovetailed with increasing professionalization of the roles formerly held by generalist savants and scientific amateurs. By the end of the nineteenth century an array of new scientific societies, with distinct membership lists and published journals, proliferated alongside the older academies and philosophical societies. The physical sciences came to have great prestige, symbolized in the Nobel Prizes.

Diplomatic and cultural historians often have claimed that in important respects, the nineteenth century ended with World War I, not the year 1900. However, not a great deal changed in the everyday scientific life of scientists after World War I, even in cases where their personal lives had been shattered. Most returned to the institutions and laboratories where they had worked before 1914, and they took up the very same problems they had abandoned for war work in 1914 or 1915. Ernest Rutherford, Jean-Baptiste Perrin, Max Planck, and Gilbert Newton Lewis all are cases in point. The journal literature of 1920 differs very little from the literature of 1913, and articles and books written during the war years were widely read and first incorporated into research agendas in the early 1920s.

The development during the 1920s of the nonclassical tenets of quantum theory constituted a conceptual "revolution" in science, but not one that immediately undermined the conceptual authority of science, for either its practitioners or its public. The general theory of relativity, for all its bowdlerization by journalists, only reinforced respect for scientific authority, as demonstrated in the fascination with and mythologization of Albert Einstein.

After 1940 things changed more dramatically than after 1919. As a consequence, the years from 1800 to 1940 have the coherence for the history of chemistry and physics that is the basis for this volume's periodization. This history is mainly about science and scientists in Western Europe and North America from the time of Napoleon I and Queen Victoria to the outbreak of World War II. It focuses mainly on institutions in France, Germany, Great Britain, and the United States. The history of the successes and failures of internationalism, in conflict with powerful nationalisms, constitutes one of this book's important themes.

This book differs from other such histories in treating *both* modern chemistry *and* modern physics. A real effort has been made to show the similarities, differences, and connections between these two disciplines as they developed out of eighteenth-century traditions of natural philosophy, natural history, and chemical philosophy.

Some very fine histories of science that sweep chronologically from antiquity to the present include physics and chemistry within their purview, and there are excellent histories of physics and histories of chemistry that concentrate on the nineteenth and twentieth centuries (see the bibliographical essay).

This book aims to bring under a single compass many of the intellectual themes that are treated in these histories. It is neither a survey nor an exhaustive history, however, and much has been omitted in the interest of maintaining a manageable number of historical subjects. These include the development of a distinction between the chemical and physical atom; the conceptual competition between theories of the discrete corpuscle (or quantum) and theories of the continuum; the evolution of a field dynamics and an energy dynamics from a Newtonian force dynamics; the ongoing interplay in chemical explanation of traditions of natural history (biology) and natural philosophy (physics); the drama of turn-of-the-century discoveries of electrons, X rays, and radioactivity; and the truly revolutionary character of quantum mechanics, relativity theory, and nuclear science.

But if much in this history turns on ideas, these ideas and their empirical manifestations were the product not only of imagination, reasoning, and craft among women and men studying natural phenomena but also of educations, careers, and ambitions in particular settings of local and national politics, technologies, and ideologies. Some of this is analyzed as well. This book does pay some attention to the difficulties faced by women chemists and physicists in Europe and North America and by black scientists in the United States. The broader global story of the physical sciences as practiced outside the North Atlantic context by both Europeans and non-Europeans is told in other volumes. The reader is referred, for example, to Lewis Pyenson's *Civilizing Mission: Exact Sciences and French Overseas Expansion, 1830–1940*, the third in his series of volumes on science and colonialism. After 1940, it is impossible to ignore developments in chemistry and physics that took place in Japan, India, the Soviet Union, and other countries outside the North Atlantic sphere.

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Disciplinary Organization in Nineteenth-Century Chemistry and Physics

Discoveries and controversies in physics and chemistry, the transmission and exchange of scientific information, and alliances, collaborations, and rivalries between and among physicists and chemists during the nineteenth century must all be set within their national and institutional contexts to be properly understood. This opening chapter, therefore, outlines the emergence and maturation of the institutions within which work in the physical and chemical sciences was performed during the nineteenth century, concentrating its attention on the development of university-level programs, research laboratories, and learned societies for physicists and chemists on the European continent, in Great Britain, and the United States. It briefly examines the development of periodicals devoted specifically to physics and chemistry and, finally, looks at the public role that these sciences had begun to assume by the nineteenth century's end. Discussion of the specific issues motivating research in physics and chemistry during the nineteenth century begins with chapter 2.

National Trends and Rivalries

In the early 1800s, institutional arrangements for the physical sciences were based in universities, government-sponsored engineering schools, academies and learned societies, and museums and observatories. Newer colleges, which oriented their curricula toward secular and practical education, proliferated in the second third of the nineteenth century, as did both specialized scientific societies and umbrella scientific organizations with national memberships. The weekly journal of the French Académie des Sciences (the *Comptes rendus hebdomadaires de l'Académie des Sciences*), which began to appear in 1835, set a new pace for a closely linked international network of communication among experimental and mathematical scientists.

During the course of the nineteenth and twentieth centuries, as the nation-state became the fundamental unit of political and military organization, nationalism and chauvinism played important roles in fostering scientific rivalries among scientists themselves and among their patrons and clients in government and industry. Scientific and technological achievements increasingly became indicators of national power and prestige. Napoleon Bonaparte fostered science and technology in France, as did Albert, the German-born prince consort of Queen Victoria, in Great Britain.

Scientists alleged a "decline of science" in Britain in the 1820s, comparing British science and mathematics unfavorably to French science, just as French scientists became concerned in the 1860s and 1870s about what they saw as the unfavorable condition of French science in comparison to that of the German states, which united under Otto von Bismarck and defeated France in military combat in 1870.

It is striking, however, that by 1900 the research productivity of physicists, in measured numbers of scientific papers, was approximately the same in England, France, Germany, the Netherlands, and the United States (and also in Japan). If allowance is made for the differences in these countries' populations, the numbers of physicists and physics students were also remarkably similar, as were expenditures for laboratories.

Most physicists were teaching or doing research in educational institutions, although some were entering engineering fields, especially as gas and electricity utilities burgeoned in the 1880s and 1890s. There was considerable consensus about the set of problems that defined the discipline of physics by 1900, including consensus on how to go about solving problems and on the best methods for training the next generation of practitioners.

In the field of chemistry, Germany by 1900 was widely acknowledged to be far ahead of other countries in the numbers of chemists