Introduction

When Western missionaries introduced the science of chemistry to China in the middle of the nineteenth century, they called it *hua-hsüeh*, which means "the study of change." The choice was a good one, and it has survived as the name for this discipline in China as well as Japan. "The study of change" captures the essence of chemistry, the branch of science that deals with the arrangement of atoms into molecules and their rearrangement to form new structures or compounds. Chemical reactions, which are all but invisible under the most powerful microscopes, may catch the eye of even the casual observer, as compounds are transformed with explosive effect or substances with unimaginable properties appear, leaving little doubt that some important change has occurred.

This book describes the study of change during its first century. We begin with the word, the problem of translating not only the name, chemistry, but a whole vocabulary connected to it, and ultimately the problem of replacing one language and associated mind-set with another. Since chemistry is central to the curriculum of modern education, we look next into China's schools, examine the students, teachers, textbooks, laboratories, and vocational workshops. In the early twentieth century, the Chinese undertook the application of chemical technologies to industry, which calls for visits to arsenals, factories, and industrial plants. As the quality and training of Chinese chemists improved, many turned to research, so we will consider the problems and sometimes stunning achievements of members of an international scientific community working in the backwaters of Asia. Finally, the expansion of these activities produced a growing body of practitioners who created societies, journals, conventions, and other symbols of a modern scientific profession. In all these ways, we will examine Chinese chemistry from the inside, to see what the chemists said and did to effect change in these corners of China.

The title has a second meaning, however, for this book also probes larger changes in China as they relate to the development of chemistry and of science in general. Foremost among these is the roller coaster profile of the Chinese state, whose descent, collapse, and resurgence help explain the inverse growth, flowering, and decay of science as an autonomous activity. Changes in Chinese society, away from the Confucian ideal of governance by an omnicompetent, classically trained elite, through the dispersion of power among diversified, technical experts, and back again to the dominance of political generalists, were both causes and effects of the parallel developments in the community of Chinese scientists. Science has had an impact on the elemental questions of knowledge, values, and understanding, and this in turn raises problems of cultural identity in a society that is trying to be both modern and Chinese. Finally, chemistry and other branches of science were never far removed from the quest for wealth and power, which has been a concern, often the chief concern, of Chinese leaders on all points of the political spectrum.

This is the study of change, from the narrow focus on one scientific discipline to the broad outlines of China's modern experience. For the benefit of those more familiar with Chinese history than with test tubes and pipettes, we will begin with a brief description of chemistry as the Chinese found it in the mid-nineteenth century. Students of science may be more interested in the following pages, which lay out major themes in the relationship between science and China's culture, state, and society.

Chemistry in the nineteenth century

When the Chinese came to this subject in the mid- to late-1800s, chemistry was already an established discipline, with its own models, methods, vocabulary, and community of practitioners, then confined largely to Western Europe. The foundation of modern chemistry dates from the 1780s, when Frenchman Antoine Lavoisier set forth a new paradigm to explain the composition and changes observed in material substances, which proved superior to the old Aristotelian and alchemical notion of the "four elements." Lavoisier also constructed a vocabulary to describe his system, bringing together the theory and language that have remained at the core of chemistry ever since. During the first half of the nineteenth century, chemists described the interactions among substances in gross proportions – the combining of "equivalent proportions" or "equivalent weights" of different materials to form new products. It was not until the 1860s that John Dalton's atomic theory gained general acceptance, bringing chemistry down to the level of the atom and the combination of atoms to form molecules. The full picture of modern molecular theory – with atoms arranged in the periodic table, valences, electrical charges, bonding, and so forth – emerged from discoveries made during the last decades of the century. In short, the roots of modern chemistry were firmly in the ground before the Chinese pulled up the plant to have a look.

Concurrent with developments in theory and laboratory practice, nineteenth-century Europe was also experiencing a revolution in the application of chemical knowledge to a wide range of practical uses. The boom in textile production that followed innovations in spinning and weaving created a corresponding demand for cleansing and bleaching agents, which was met with new techniques for the manufacture of sulfuric acid, bleaching powder, and soda. In surgery, chemical anesthetics introduced in the 1840s – nitrous oxide, ether, and chloroform – reduced pain, and antibiotics, first used by Lister in 1865, lowered the incidence of infection and death. Beginning around 1850, European agriculture profited from the introduction of chemical fertilizers: superphosphates, ammonium sulfate, sodium nitrate (Chile saltpeter), and potassium sulfate. Mining and warfare were advanced by the development of nitroglycerine, dynamite, and other high explosives. Toward the end of the century, a whole new chemical industry was constructed around the synthesis of organic drugs and dyes.

The most telling feature of nineteenth-century chemistry was not that a new scientific discipline had come of age or that chemical products were changing the economy of Europe, although both were important, but that the two sides of chemistry, the science and the technology, had been alloyed. On one hand, changes in technology led to breakthroughs in science. The rise of steam power and developments in mining, industry, and transportation called forth new responses from the laboratory. The manufacture of coal tar derivatives, chemical reagents, improved glass, metal alloys, and other products made the work of the scientist in some cases possible and in all cases easier. The opposite was also the case, for professional chemists whose main purpose was to investigate the working of nature produced knowledge and methods that were applied outside the lab. In France, physician Nicolas Leblanc invented a method for making industrial soda from common salt. Leblanc was followed by Clement, Desormes, and Gay-Lussac, other Frenchmen who helped improve methods for the large-scale manufacture of sulfuric acid. A young English chemist, William Perkin, in the course of experiments designed to make the drug quinine, produced the first synthetic dye. Perkin's breakthrough was more fully exploited in Germany, where during the last decades of the century, chemical industry, education, and research were first brought together to create the synergy that is so characteristic of modern science-based economies. The work of Boussingault and Liebig on plant nutrients, of Pasteur on the chemical basis of fermentation, disease, and other aspects of microbiology, and of Haber and Ostwald on the synthesis of ammonia and nitric acid all demonstrate the interdependence between chemical science and chemical technology.

The cutting edge of chemistry migrated in the course of the nineteenth century from France and Britain to Germany. Lavoisier, a Frenchman, based his theories on the experimental work of Englishmen Cavendish, Priestly, and Boyle and of Scotsman Black. Other names, French, British, Italian, and German, came to populate this Pantheon during the early nineteenth century. But by 1860, it was the Germans – Lieber, Wohler, Kolbe, Bunsen, and Kekule – who rose above the landscape of European chemistry. Britain remained the world's leading producer of the "heavy" industrial chemicals, acids and sodas, while Germans dominated the "fine" chemicals, dyes and drugs, and made almost all of the important breakthroughs in chemical technology during the decades before World War I. Americans played no part in the science of chemistry and only a minor role in the chemical industries of this period.

In sum, the chemistry that was introduced to China after 1850 came in the form of a well-organized, well-articulated body of ideas and instrumentalities. It had emerged from behind the dark veil of alchemy and the recesses of Europe's iron and coal mines to an honored place in the academy, and boasted all the theories, methods, journals, conferences, and other paraphernalia that mark the arrival of an independent discipline. Chemistry helped to create the wealth and power of the West and bring the undeniable might of modernity to the shores of East Asia. The Chinese would learn of chemistry through the translation of English-language sources, even while the leading edge of this discipline was moving to Germany, but this made little difference since China had no prior experience with these matters and needed the most basic information.

The choice of chemistry as the focus for this book was not a difficult one. One purpose of the study is to portray science in its interactions with modern China, and we will cast our glance from time to time across this broad landscape. But there is a danger that pictures taken with a wide-angle lens might miss too many details, so it seemed wise to pick one discipline, and chemistry had much to recommend it. Chemistry had the greatest impact of any branch of science on the world of the late-nineteenth and early-twentieth centuries. It transformed medicine, saving lives and ushering in the global population boom; agriculture and industry, making possible rapid, sustained economic growth; materials, changing the substance, color, and shape of our surroundings; and warfare, enabling us to destroy one another with greater effect. For these and other reasons, more Chinese chose to study chemistry than any other branch of science. There were more Chinese chemical teachers, researchers, institutes, publications, societies, and industries than in any other field. Among the sciences, chemistry penetrated most broadly and deeply into the fabric of China and did the most to change life in that country.

There is a second factor, less a reason for selecting this discipline than a benefit of a choice already made, namely, that chemistry is one of the physical sciences and is without precedent in China. During the period in question, the descriptive sciences – geology, biology, meteorology – relied, as the label implies, on taxonomy or classification, which could be performed with simple tools and related to elemental theories, readily accessible to novices and laymen. These are "local" sciences that rely on the accumulation of data, collected in the field or from historical records, that describe the flora, fauna, and topography of a particular place. These features made the descriptive sciences attractive to many Chinese scholars, who could quickly enter the game of world science, contribute to the nation at home, and gain recognition from the scientific community abroad, simply by reporting on what they found in their own backyards. Chinese who chose this route played at the low easy end of the scientific spectrum, often with early favorable results. The physical sciences – physics, chemistry, and astronomy – have all of the opposite characteristics: They depend on elaborate equipment, abstruse theories, complex experimental procedures, and data that are the same everywhere. Little in China's natural environment or library of traditional scholarship gave Chinese scholars a leg up. The challenge was frightening, but those Chinese who chose chemistry played in the big leagues of international science, and this gives their story added appeal.

Science in China and the West

Chemistry is one branch of "science," a difficult and elusive term that raises a number of interesting questions. As used here, science means that special set of models and methods for explaining the behavior of material phenomena, which issued from the great Scientific Revolution of seventeenth-century Europe. Science embodies a distinct approach to nature, a way of acquiring information, fitting this information together into theories, testing the theories against new data, and modifying or replacing these theories as the dialogue proceeds. It is a continuous tradition of ideas, methodologies, and social practices, all of which are devoted to capturing an ever more accurate picture of the universe. And it has won out against competing approaches through its ability to produce convincing, useful results.

This definition of science raises a number of questions, the first of which is the relationship between science and those explanations or models of nature developed in other times and places, including pre-modern (or pre-Western) China. It may be, as Joseph Needham has argued, that science is the outcome of a "grand titration" that has drawn together the contributions of many nations. Even so, the science that emerged from Europe in the nineteenth century was unrecognizable to the Chinese, who had to discover, adopt, and adapt it along with other strange new things from the West. There were, of course, links between traditional Chinese and modern Western nature studies: Chinese astronomers and mathematicians of the seventeenth century learned from Jesuit missionaries of recent European breakthroughs, which they adapted to Chinese astronomy, raising this discipline to new heights. Early recruits to science in the nineteenth century came to this subject through study of ancient Chinese texts and translations handed down from the Jesuits and their Chinese converts. Chinese scholars of the late Ch'ing dynasty (1644–1911) took great pains to square the new science with the classical concept of the "investigation of things." But connections of this type were tenuous and fleeting. With the passage of time, the gap between traditional Chinese and modern Western approaches to nature widened. Chinese science did not grow organically from the study of *yin* and *yang*, the "five elements," the principles of *li*, or the forces of *ch'i*. Rather, science entered China through a side door, and Chinese who studied chemistry and other disciplines took lessons directly from the West, often oblivious to the treasures of their own past.

This is not to say that the delivered culture played no role in this story. On the contrary, traditional approaches to learning, values, and habits of mind have had the greatest impact – for better and worse – on the study of science in China. Classical learning fostered a respect for scholarship, a care in organizing and preserving factual information, and training in memorization, all of which are virtues in the scientist. On the other hand, the bookishness, the preoccupation with philosophical and literary subjects, denigration of manual and technical skills, and undue respect for established authority often left the classically trained scholar unfit for the laboratory, field, or workbench. The point is that the interplay of tradition and modernity lay less between competing explanations of nature, than between Western science and the broader values and ideas that permeated Chinese society and culture.

A second question raised by this definition of science is its relationship to technology. Although the two should not be confused, they are closely connected and will be treated in tandem throughout this book. Science is a way of understanding or explaining nature. Technology is an instrument for manipulating or changing it. It is safe to say that there would be no science without the tools, starting with broken stones, through which man has interacted with his surroundings. Conversely, while their early development had little to do with a systematic view of nature, most modern technologies are "science-based." Both the conceptual distinction and practical connection between science and technology are amply demonstrated by the case of chemistry in China. Chinese scientists sometimes acted as though the two were separate, pursuing pure or basic research while ignoring problems close at hand. But the demands of China's economy and the pressure of government officials shifted attention back to practical applications. Science and technology are both mutually supportive and competitive, and at the end of China's first century of science, the tension between them remained unresolved.

A third question is the relationship between science and culture: whether science is limited to material objects of nature, or extends to human behavior and beyond? For many in China (and elsewhere) science has had a very broad meaning: in some cases a model or law, in others a set of methods and principles, and in either instance applicable not only to material objects, but to all things. At one extreme were the Marxists, whose law of dialectical materialism purports to explain everything from the big bang to the coming utopia. The Marxists enjoyed a large following in pre-1949 China, and philosophers in the Communist Party made ambitious claims for their ideology. Even more popular, particularly during the 1920s, was the devotion to scientism, the idea that the models and methods of science have universal applicability and should, therefore, replace the discredited Confucianism as the basis for China's "New Culture." In a society as unsure of itself as twentieth-century China, science could not be contained in the laboratory alone. But not all Chinese welcomed such radical ideas. In particular, conservative elements of the Kuomintang, who gained sway during the Nanking Decade (1927–37), wanted to use science and technology to enhance the power of the state, at the same time insulating traditional values against infection by foreign ideas, scientific or otherwise. There was, in the end, no agreement on China's identity or the place of science in it, but enormous interest in the question and a willingness on all sides to provide the answer.

Science, state, and society

Science is an idea, a way of understanding or explaining things, and can therefore be studied as intellectual history, the process by which one paradigm or picture of the universe displaces another. It is also a social activity, a set of values and beliefs, a means of relating and communicating ideas among people. Much of the history of science adheres to the former definition, and appropriately so, for its main concern has been to describe the evolution of man's image of nature, the way new facts are discovered and better concepts devised. In the case of China, however, the problem is not to trace the pattern of ideas, for it might be said that there was no pattern, at least in the period covered by this study, because scientists in China addressed piecemeal the questions posed by scholars in the West, and Chinese science developed without systematic coordination or agenda. This means that the more interesting question has been sociological, namely, What has been the relationship between Chinese science and the political and social context in which it emerged?

The answer presented in this book is that science rose and fell along with the rhythms of change in Chinese state and society. During most of the nineteenth century, the Manchu rulers and their Chinese allies shared an interest in limiting the penetration of new ideas and groups and succeeded in keeping both under control. Some small moves cracked the door to modern science and technology. Treaties signed with the Western powers admitted missionary doctors, teachers, and translators who came to China with knowledge of science and the desire to share its secrets. Chinese "self-strengtheners" established arsenals, shipyards, schools, and translation bureaus and sent students abroad, all for the ships, guns, and secrets of making them, needed to protect the empire against rebellion at home and invasion from abroad. But this is as far as the Ch'ing dynasty would go. The dominant, conservative forces in Peking rebuffed attempts to broaden the curriculum of the civil service exams, by which officials were chosen, or the scope of industrialization, which would have created greater demand for new knowledge and skills. Even the more progressive self-strengtheners in the provinces recruited and promoted men with classical backgrounds, while ignoring those with technical expertise. Finally, changes in local society – the "fusing" of merchant and gentry classes, their growing separation from the state, and the creation of an autonomous "public" managerial elite – failed to expand the market for technical skills.

Given this lack of hospitality, few people in nineteenth-century China took a serious interest in science or understood its message. The most persistent and effective proponents were Protestant missionaries, who led in creating a Chinese scientific language, translating and publishing texts, and establishing schools to teach the new ideas. A handful of Chinese, men who had failed the classical examinations and had an off-beat interest in nature studies, joined the missionaries as partners in the translation business. A somewhat larger number studied science in government and missionary schools or read the translations on their own. But this group was small and its horizons limited. So long as classical learning remained the favored credential, scholarly talent was drawn to this pole, students of science had difficulty finding work, and members of the literati who dabbled in science confused its message with traditional categories of thought. The vice of political and social authority was tight, the incentive to take up strange new studies weak, and the development of science correspondingly slow.

All this changed in 1895, when the defeat in the Sino–Japanese War shattered China's complacency and opened the country to revolutions of every kind. Like the peeling of an onion, the layers of the old order – the dynasty, the imperial system, central authority, and Confucian culture – were stripped away, leaving an emptiness that invited radical change. The Manchus made a last-ditch effort to save themselves by adopting modernizing reforms, before succumbing to the Revolution of 1911. Military strongman, Yuan Shih-kai, held the new Republic together for a time (1912–16), but after his death China was torn apart by warlords (1916–27), none of whom could unify the country or remain satisfied with only one piece of it. Meanwhile, the traditional elite and the Confucian ethic on which their authority rested were swept aside by a firestorm of social and cultural iconoclasm that left few charred remains.

The collapse of the old order had some positive effects on the development of Chinese science. Governments of the late Ch'ing and early Republic began to promote the study and application of science, either to increase the nation's wealth and power, or simply because they sensed the need for modern solutions. Even elements of the old Confucian elite recognized the necessity for change. But the chief point about this interregnum – the period from 1895, when the downward slide of the empire began, until 1927, when the Nationalists restored a measure of central authority – is that the absence of political and social form left the field open to a variety of forces, some of which established the first real foundation for the study and practice of science in China.

As the state lost control, three groups that favored the development of science, but had previously been held down, surged forward. First were the foreigners: governments, missionaries, and philanthropists. Western missionaries were the most important force behind science in China in the nineteenth century, but their influence had been contained. After 1900, the U.S. government, through remission of the Boxer indemnity, and the Rockefeller Foundation joined the churches in making scientific education and research available in greater quantity and quality to more Chinese at home and abroad. Second was the new urban, Western-oriented Chinese intelligentsia. These men, and now also women, created and promoted the New Culture that was to replace the Way of the Sage and connect China to the mainstream of the modern world. Few were scientists in the strict sense of the term, but many had been introduced to scientific ideas and applied them in shaping the society and culture of the 1910s and 1920s. Third were Chinese investors and entrepreneurs, who introduced new technologies based on a knowledge of science and called forth the services of a trained technical elite. The scope of economic change was still narrow, but the thin edge of the wedge was in the log.

Whereas the collapse of the old order cleared the field for new forces, the absence of effective political authority and accepted social norms left few structures to support and coordinate their scattered initiatives. There was in early twentieth-century China no escape from violence and chaos, no reliable source of funding and organization, no insulation of scholarship or industry against the winds of fate. It was good for Chinese science that the too-strong, too-conservative empire had been destroyed and the door to innovation opened, but bad that the door had come off its hinges. Some sort of order was needed, and missing.

If the problem of the nineteenth century was too much authority and the early twentieth century too little, then the Nanking Decade (1927–37) was just right for the development of Chinese science. During this brief period, the Nationalist or Kuomintang regime provided the unity and commitment needed to carry out a program of research, education, and the application of new knowledge to economic development and national defense. The Nationalists channeled money and people into the study of science in colleges, universities, academies, and institutes. They supported the introduction of new technologies in public and private enterprises. They established security, stability, and a sense of direction that attracted educated Chinese to return home and gave them confidence in the future. In all these ways, the Nationalists restored the central coordinative power of the state and placed it behind a program of scientific and technical development.

There was a temptation to overdo it, however, to place too tight restrictions on those forces that had emerged during the preceding decades and stifle the free flow of resources, people, and ideas that are essential to scientific and technical growth. The heightened sense of nationalism and the ability of Nanking to enforce nationalist demands, placed foreigners, particularly missionaries, under duress. Some elements of the new regime wanted to rein in the mission colleges, which had led the development of scientific education in the 1920s. Another target of the ultranationalists was the scientists themselves. Many members of China's new intelligentsia, men and women trained in the world's leading universities, had earned membership in the international scientific profession. This identity carried with it a faith in the importance of specialized knowledge, the right to establish an agenda in areas such as education and research that lay within their sphere of expertise, and to autonomy from the larger social and political environment. The Kuomintang right viewed the scientists with suspicion, pressured them to adopt a more utilitarian approach aimed at increasing the wealth and power of the state, and rejected the quest of knowledge "for its own sake." Finally, Chinese entrepreneurs, who led in the introduction of new