***BSHS Monographs* publishes work of lasting scholarly value that might not otherwise be made available, and aids the dissemination of innovative projects advancing scholarship or education in the field.**

13. Chang, Hasok and Jackson, Catherine (eds.). 2007. *An Element of Controversy: The Life of Chlorine in Science, Medicine, Technology and War.* ISBN: 978-0-906450-01-7.

12. Thackray, John C. (ed.). 2003. *To See the Fellows Fight: Eye Witness Accounts of Meetings of the Geological Society of London and Its Club, 1822-1868*. 2003. ISBN: 0-906450-14-4.

11. Field, JV and James, Frank AJL. 1997. *Science in Art.* ISBN 0-906450-13-6.

10. Lester, Joe and Bowler, Peter. *E. Ray Lankester and the Making of Modern British Biology.* 1995. ISBN 978-0-906450-11-6.

09. Crosland, Maurice. 1994. *In the Shadow of Lavoisier:* ISBN 0-906450-10-1.

08. Shortland, Michael (ed.). 1993. *Science and Nature.* ISBN 0-906450-08-X.

07. Sheets-Pyenson, Susan. 1992. *Index to the Scientific Correspondence of J. W. Dawson.* ISBN 978-0-906450-07-9.

06. Morris, PJT, and Russell, CA; Smith, JG (ed.). 1988. *Archives of the British Chemical Industry, 1750-1914: A Handlist.* ISBN 0-0906450-06-3.

05. Rees, Graham. 1984. *Francis Bacon's Natural Philosophy: A New Source.* ISBN 0-906450-04-7.

04. Hunter, Michael. 1994. *The Royal Society and Its Fellows, 1660-1700.* 2nd edition. ISBN 978-0-906450-09-3.

03. Wynne, Brian. 1982. *Rationality and Ritual: The Windscale Inquiry and Nuclear Decisions in Britain.* ISBN 0-906450-02-0

02. Outram, Dorinda (ed.). 2009. *The Letters of Georges Cuvier.* reprint of 1980 edition. ISBN 0-906450-05-5.

01. Jordanova, L. and Porter, Roy (eds.). 1997. *Images of the Earth:* 2nd edition. ISBN 0-906450-12-8.

For e-prints and ordering information, visit the BSHS Monographs Website: www.bshs.org.uk/monographs

An Element of Controversy

The Life of Chlorine in Science, Medicine, Technology and War

Edited by Hasok Chang and Catherine Jackson

from research by undergraduate students at
University College London

British Society for the History of Science

2007

ISBN 978-0-906450-01-7

Cover design by Joe Cain.

Front cover illustration: Blueprint for a chlorine chamber for the cure of respiratory diseases. Reproduced by permission of Edward G. Miner Library, Rocherster, New York.

Back cover illustration: Chlorine gas, courtesy of the Department of Chemistry, University College London. Photo by Gretchen Siglar.

Contents

Introduction

Hasok Chang and Catherine Jackson

One spring day in 1915, Allied troops lay writhing in agony in the fields of Ypres, Western Belgium, from a deadly gas attack that opened a new chapter in the history of warfare. Nine years later President Calvin Coolidge of the United States sat in a specially designed chamber breathing the very same chemical, and afterwards pronounced himself much relieved from his cold. That gas, yellow-green, suffocating and corrosive, had been isolated for the first time in 1774 by the Swedish chemist Carl Wilhelm Scheele, who called it "dephlogisticated muriatic acid". After a few decades of fierce academic debate the substance became recognized as a chemical element, named "chlorine" by Humphry Davy, and it has continued working its way into various aspects of our lives to this day. In fact chlorine was always around in human life, being one half of common salt (sodium chloride) among other things, though people were very slow in recognizing its identity.

This book tells the story of chlorine, one of the most common yet unusual substances that make up our physical universe. It is a work in the category of "object biography", which has become rather popular in recent years. We believe that it is a genre with much potential. Especially in the area of history of science, the object-focus is very effective in highlighting connections that are obscured by the usual focus on ideas, institutions, and individual scientists. The story of chlorine's life is full of wonder, mystery, danger, and most of all controversy, both intellectual and political. In a personal biography, one might say that the common line running through the various stories of an individual's life is his or her character; here we find that the highly reactive chemical character of chlorine is to a large extent responsible for its controversial life, both in chemical theory and in its often destructive practical applications. Any good biography also tells much about the society in which the protagonist lived. Thus our biography of chlorine is also an important slice of the story of how science has developed and become such an integral part of

Hasok Chang and Catherine Jackson, eds., An Element of Controversy: The Life of Chlorine in Science, Medicine, Technology and War *(British Society for the History of Science, 2007).*

modern life through its technological, medical and military applications. The time span we cover is about two centuries, so it is impossible to be exhaustive in our account; however, our selection of events and issues will portray a well-rounded picture of an extraordinary life.

The studies contained in the book were carried out by five successive cohorts of undergraduate students at the Department of Science and Technology Studies at University College London, each year's group building on the work of the previous one. As the research was done by students who were eager to rise up to the highest academic standards, yet still relatively free from the need to sound learned for the sake of sounding learned, we believe we have reached a happy combination of rigor and accessibility. In the Epilogue we give a more detailed description of this fascinating and exciting experience, which will be of interest to those concerned with the practice and theory of higher education. The editors are responsible for the overall organization of the book and the presentational work to ensure consistency in style, as well as some follow-up research to fill in small gaps. However, credit for the content of the book belongs unequivocally to the authors of the individual chapters, and they are also responsible for the lively spirit of the whole enterprise that shines through all of the chapters.

The eleven studies contained in the book tell independent stories, with some close connections between them. Readers may sample individual chapters according to their particular interests, or read them through in the order presented to get a full sense of the life of chlorine. To aid the latter approach, we have organised the material in roughly chronological order for the most part. At the same time, for ease of thematic reference we have grouped the chapters into two parts. Part A includes debates about the nature of chlorine as a chemical and physical substance, and the place of these debates in the development of the theory of matter. Part B treats episodes arising in the diverse practical applications of chlorine and some of the most important chlorine compounds.

In Chapter 1, Ruth Ashbee gives an account of the complicated birth of chlorine. When Carl Wilhelm Scheele first discovered chlorine in 1774, he called it "dephlogisticated muriatic acid" ("muriatic acid" in modern terms is hydrochloric acid, or *HCl*). But this was in the thick of the Chemical Revolution, in which Antoine-Laurent Lavoisier's oxygen theory was rapidly displacing the phlogiston theory, which was the basis of Scheele's thinking. It is tempting to conclude that Scheele was simply an adept experimenter who lacked the theoretical resources to reach a correct understanding of what he had discovered. However, our study of Scheele shows very clearly that he was a sophisticated theorist, and his interpretations do make a lot of sense in their own terms. If we were to take the modern point of view, we would find that the Lavoisierian interpretation was just as wrong: Claude-Louis Berthollet, Lavoisier's colleague who studied chlorine most closely, concluded that it was "oxygenated muriatic acid". It is not simple to say which side was more correct in this debate. What we have here is a case of incommensurability, which we can understand best in terms of conflicting "lexical structures" as conceived by Thomas Kuhn in his later writings following the *Structure of Scientific Revolutions*.

In Chapter 2, Tamsin Gray, Rosemary Coates and Mårten Åkesson follow the fierce chemical debates about the nature of chlorine that continued in the aftermath of the Chemical Revolution. The architects of the new chemistry, with the confidence of their general triumph, continued to uphold two beliefs about chlorine that are wholly rejected by modern science: they thought that chlorine was a compound of oxygen and muriatic acid, and that muriatic acid was a compound of oxygen and the "muriatic radical". It was only by 1820, due to the work of Humphry Davy among others, that chemists arrived at a consensus that chlorine was a chemical element, isolated by removing hydrogen from muriatic acid. The new theory of chlorine did not prevail easily, as shown in the stories of three major chemists who challenged the emerging consensus: not only Berthollet, but John Murray in Scotland, and Jöns Jakob Berzelius in Sweden. This episode completes our view of the Chemical Revolution seen through the case of chlorine, in which the winners are quite as mistaken as the losers if we judge them according to modern ideas. These debates also illustrate the extreme difficulty of reaching clear and unambiguous theoretical interpretations of even the most basic phenomena.

After chlorine was recognized as a chemical element, it became important to determine its atomic weight. The best empirical values clustered around 35.5; this presented a problem for those who supported William Prout's hypothesis that all atomic weights were whole-number multiples of hydrogen's weight (defined as 1). Prout's hypothesis has been celebrated by many modern scientists and historians of science as the anticipation of the idea that atomic nuclei are composed of a discrete number of protons and neutrons. In the end the idea of isotopes made sense of the non-integral atomic weight of chlorine, as chlorine naturally occurring on earth came to be seen as an accidental 3:1 mixture of two isotopes, weighing 35 and 37 respectively. Each isotope of chlorine was then seen to conform to Prout's hypothesis. As carefully recounted by Jonathan Nendick, Dominic Scrancher and Olivier Usher in Chapter 3, the way chemists dealt with chlorine before the discovery of isotopes reveals some interesting points about the scientific method, particularly in reference to the discussion of this episode by Imre Lakatos as an illustration of his methodology of scientific research programmes. Some chemists, by wishful thinking or experimental imprecision, estimated the atomic weight of chlorine as 36; some proposed a modification of Prout's hypothesis taking *half* of hydrogen as the fundamental unit; some simply put chlorine on hold, hoping for some unexpected resolution of the anomaly; others regarded chlorine as a refutation of Prout's hypothesis, and thereby discarded a promising and pioneering theoretical idea.

In Chapter 4 we continue on to the 20th century, when chlorine found itself in the middle of yet another complicated debate in the theory of matter, as elucidated by Christian Guy, Emma Goddard, Emily Milner, Lisa Murch and Andrew B. Clegg. It was predicted that the heavier isotope of chlorine (^{37}Cl) would occasionally interact with the neutrino, the most elusive of elementary particles, which had been written off as undetectable. The chlorine–neutrino interaction would produce radioactive argon atoms, which could be swept up by bubbles of helium gas, and then isolated and counted up. This fantastic scheme was realized in an experiment in which physicists buried a huge vat of dry-cleaning fluid (C_2Cl_4) in the Homestake gold mine in South Dakota, aiming at the first-ever detection of neutrinos emerging from the interior of the sun. The success of this and other similar experiments, however, plunged physicists into a deep quandary. The detected flux of neutrinos was much less than had been predicted by the standard theory of the nuclear reactions taking place inside the sun. Debates on this issue still continue today, but physicists have now converged on the unexpected solution of "neutrino oscillations": neutrinos have a tendency to change their form in transit between the sun and the earth, lowering the detection rate where the detector is only designed to capture them in their original form. This episode also reminds us of some difficult philosophical questions about what can be considered an "observation". Physicists commonly say that they make direct observations of the solar interior by means of neutrinos, but shouldn't they really admit that they are only making a long chain of inferences going from the detection of radioactive argon to the nuclear fusion in the sun? Philosophers such as Dudley Shapere emphasize that scientific observations are routinely indirect and we have no choice but to rely on our best theories. However, if we allow theoretical inferences to form the basis of observations, then we must also say that neutrinos were observed long before Homestake.

In discussing the practical applications of chlorine in Part B, we begin with a striking property of chlorine that was apparent right from the beginning. When Scheele first isolated chlorine, he immediately noticed that it had the power to destroy "vegetable colours". On the face of it, it would seem that this should have led rapidly to industrial and commercial applications, especially given the strong demand for cheap and quick bleaching methods in the burgeoning textile industry during the time of the Industrial Revolution. The actual history was rather different. As Manchi Chung, Saber Farooqi, Jacob Soper and Olympia Brown recount in Chapter 5, it was a long and complex process to turn the idea into a usable and economical technology. This case reminds us of the general inadequacies of the "linear model" of technological development, according to which new discoveries spontaneously arising in pure science are straightforwardly applied to create useful technologies. The importance of contextual factors is shown clearly in a comparative history of chlorine bleaching in France and Britain. In France, the initial pattern of development was driven by central government, as would be expected according to a common view of French science during this period; however, the French Revolution disrupted the governmental structure so much that private enterprise came to play a crucial role. In England the role of the state was minimal from the start, and the development of chlorine bleaching was left to the "scientist–entrepreneurs" such as James Watt, gentlemen opportunists who played the topsy-turvy material and social world of the Industrial Revolution to their own advantage.

Many of us are familiar with the presence of chlorine not only in bleaches, but in swimming pools, household disinfectants, and the water supply. We might imagine that the promoters of public health would have quickly seized on the disinfecting power of chlorine and many of its chemical compounds. On the contrary, as Anna Lewcock, Fiona Scott-Kerr and Elinor Mathieson explain in Chapter 6, the development and application of chemical disinfection was a long and frustrating process. Starting with the muriatic-acid fumigation of the Dijon Cathedral in 1773 by Lavoisier's colleague Louis-Bernard Guyton de Morveau, many attempts were made to use chlorine and various chlorine compounds to stop the spread of contagious diseases, but these practices failed to take root for a century. Time and again we witness a promising employment of chlorine, only to see it become neglected and forgotten after a period. It was only with the establishment of the germ theory of contagious diseases that disinfection by chlorine (or by other chemical means) became truly established. Without a convincing explanation of why disinfection worked, successful practices were discounted as accidental outcomes. In addition to a general survey of the history of chlorine disinfection and the theories of disease in the 18th and 19th centuries, we also offer an in-depth analysis of the controversy surrounding chlorine disinfection at the time of the cholera epidemic of 1831–32 in Britain and the United States.

In Chapter 7 we move on to examine another destructive aspect of chlorine's character, which made it a crucial material in the history of the early 20th century. It is not just bacteria that are attacked by chlorine. Chlorine gas was the first major chemical weapon to be employed in warfare, introduced during the First World War. Its first battlefield use was by the German army in 1915; retaliation in kind by the Allies followed, and a dizzying array of other chemicals came to be used by both sides. It may seem that the use of any available new technology in war is simply a natural thing, but there were also various reasons against the introduction of chemical weapons. Not only was their use prohibited in the Hague Convention, but their actual military utility was also quite questionable. Therefore, the political decision to authorize their use deserves some historical scrutiny. As Frederick Cowell, Xuan Goh, James Cambrook and David Bulley explain, in the case of Great Britain it seems that the initial aversion to chemical weapons within the government yielded to a mechanical logic of response-in-kind. This lack of deep policy-thinking is revealed in the fact that much of the conduct of chemical warfare was delegated to Major Charles Foulkes, a relatively minor military figure put in charge of the Special Brigade for gas warfare.

The British response to the initial German gas offensive was ill-prepared and haphazard, and the offensive use by the British was limited by the fact that gas tended to be used simply to make up for a shortage of conventional ammunition. The lack of strategic thinking prevented the full military potential of chemical weapons from being realized.

Despite the apparent lack of soul-searching within the government and the military, the use of chlorine and other toxic chemicals as weapons did result in a public outcry. In Chapter 8, Abbi Hobbs, Catherine Jefferson, Nicholas Coppeard and Chris Pitt explore the ethical and political debates about the use of chemical weapons following the war. Was there a cogent philosophical basis for arguing that chemical weapons were morally more reprehensible than conventional weapons? If not, why did they generate such adverse public reactions? Contrasting ethical frameworks were applied to the question of chemical warfare by different thinkers, even within the military and governmental establishments. Against Foulkes's instrumental rationality of using whatever he thought would promote the military objectives, General Peyton March of the U.S. Army objected to the use of gas because it was an indiscriminate weapon that did not preserve the principle of non-combatant immunity. The British General Sir John French deplored gas as an unchivalrous weapon, in the face of which all the character and skills of a good soldier were rendered useless. J. B. S. Haldane, renowned physiologist and active participant in gas-warfare research with first-hand experience of the effects of gas, shone the cold light of utilitarian logic on the issue by arguing that chemical weapons were actually preferable to conventional ones because they caused less suffering. Meanwhile, public reaction turned decisively against chemical weapons in the aftermath of the war, although it was rather mixed during the war. This reaction did not result simply from people's natural revulsion, but was driven by a concerted effort by the League of Nations to restore the international control of warfare after the clear violations of the Great War left the Hague Convention in tatters.

In Chapter 9, David Nader and Spasoje Marčinko trace the rise and fall of the "chlorine chamber". For a brief period after the First World War, breathing a low concentration of chlorine was widely believed to cure and prevent influenza, the common cold, and other respiratory diseases. This chlorine-chamber fad is perhaps one of the strangest and most fascinating episodes in the life of chlorine. Though its life was short, in its heyday the chlorine chamber was showcased to great acclaim at the U.S. Congress, and counted even President Calvin Coolidge among its grateful users. Who promoted this bizarre idea, how, and why? The birth and spread of chlorine as a therapeutic agent can primarily be seen as an attempt by the U.S. Chemical Warfare Service to gain public and governmental support for continuing research into chemical weapons. But why was the idea of chlorine therapy not immediately discredited, once tested out? Interestingly, it does seem that chlorine-inhalation was just as effective (or ineffective) against the flu and the common cold as any other available treatment. At the time little was known about viruses, and treatments were rudimentary. There was clear space for innovative ideas after the influenza epidemic of 1918–19, which killed an untold number of people, estimated at 20 to 40 million worldwide; the medical establishment was in crisis, and chemists were enjoying newly found prestige from their role in the war. But soon enough significant criticism was raised by the medical establishment, and the Chemical Warfare Service quietly dropped the chlorine chamber after finding more promising instruments of peacetime self-promotion, such as insecticides.

In Chapter 10, Sam Raphael, George Kalpadakis and Daisy O'Reilly-Weinstock investigate the responses of scientific communities to war, through some key episodes involving the military uses of chlorine and chlorine compounds. If science changed the face of warfare, warfare changed science just as much. Historians have clearly documented the changes introduced to science as a result of the Manhattan Project during the Second World War and other large-scale military projects since that time. In the life of chlorine, there are two phases in which the impact of war on science became clear. During the First World War, the necessity to understand the physiology of chlorine and other poison gases brought the physiologists out of their relative isolation, making them an integral part of the political decision-making process and changing the way their own community was structured. A less benign and more disruptive case was the dispute over the use of chlorine-based herbicides (including the notorious "Agent Orange") in Vietnam by the U.S. military, which pitted governmental and civil scientists against each other in a battle for public credibility. In the course of this episode, there was a shift of perceived authority from the government to the civil scientific community. Interestingly, this "authority shift" was not the result of any significant new scientific knowledge being discovered by the winning side. An important context of the shift was what Ulrich Beck terms “reflexive modernization”, in which more and more groups compete for authority, resulting in a widespread consciousness of the inherent plurality of knowledge.

The controversial herbicides discussed in Chapter 10 are only a small group within the class of organochlorines (organic chlorine compounds), which also include nerve gases, dioxin and DDT. These compounds have achieved notoriety because of their toxic effects on animals and people, which are multiplied by their persistence and accumulation in the environment. Some environmentalists have called for them to be phased out entirely. The uproar about organochlorines began most distinctly with the publication of Rachel Carson’s 1962 masterpiece, *Silent Spring*, which delivered a scathing exposé of the effects of DDT. In Chapter 11, Kimm Groshong investigates how this text was heavily criticized as a piece of unscientific emotionalism offered by a non-scientist, despite Carson’s extensive research and scientific expertise. Very few attempts were actually made by her critics to point out specific problems in the text, and most scientists now agree that it contained no major inaccuracies. A question then arises as to how these early attacks were motivated, and why they still echo widely in commentaries on *Silent Spring* today. The chemical industry and its associates had no way of discrediting Carson’s book other than repeating as often and as publicly as possible the unsubstantiated claims of *Silent Spring*’s inaccuracy, bias, and reliance on rhetoric. Many of those who published critical comments and reviews of Carson’s book were enraged by her attempt to awaken the public about the extent to which it was blindly ceding power to the growing science–industry–government complex. The noisy response was therefore a natural result of the context into which the book was published.

In each chapter we examine the life of chlorine through a particular controversy. Our main aim in focusing on controversies is not to arrive at a general view of how controversies arise and get resolved, though we do hope to have provided some useful material for that purpose. Rather, we use controversies primarily as analytical tools. Controversy exposes what agreement hides. When there is a sharp disagreement on a focused topic, people tend to reveal their deep-seated assumptions and intentions, which may not come to surface when there is nothing to argue about. The revelations are made either in articulated arguments, or in unspoken ways through actions. Our studies of the chlorine controversies repeatedly touch on some central historical, philosophical and sociological themes, which are worth highlighting here.

Theory-choice. All chapters in Part A contain controversies about the choices scientists make between competing theories, and we see very interesting exhibitions of key factors that direct the choices. In each case we puzzle over a consensus reached on the basis of what seem like inconclusive arguments. In Part B this philosophical theme of theory-choice is less explicit, but it enters the narratives in interesting ways in Chapter 6 and 9 (regarding theories of infectious diseases), and Chapters 10 and 11 (regarding theories about the environmental impact of organochlorine substances).

Symmetry and whiggism. Among professional historians of science, it has long been a taboo to commit the sin of "whiggism" or "whiggishness", in which past events are seen as steps leading toward the present (or as failures to live up to that trend). In the sociology of scientific knowledge "impartiality" and "symmetry" are two key methodological tenets, according to which we treat successful and unsuccessful ideas on an equal footing and try to explain their development and acceptance by reference to the same kind of factors. Our stories are not whiggish, but we also do not shrink from making our own judgments about which ideas were reasonable or sensible and which ones not, and quite often our judgments are in sympathy with the "losers". This methodological issue is pertinent to most of the chapters.

Science–technology relations. Recent historians and sociologists of technology have strongly disputed the traditional "linear model" of technological development, which assumes that scientific ideas arise spontaneously first, and then find appropriate practical applications. Some of our studies in Part B add cases and reflections in that direction. In Chapter 5 (bleaching), Chapter 6 (disinfection) and Chapter 7 (chemical warfare), we find interesting struggles in turning obviously promising ideas into effective and acceptable technologies. In Chapter 9 we see a very complex shaping and subsequent unravelling of a much-heralded new medical technology, in which the practical application of a pioneering idea was driven by political factors.

The politics of scientific and technological research. In all of the chapters in Part B, politics enters as a decisive factor shaping the direction of research in science and technology. This is perhaps not surprising in general terms, but our studies are instructive in illustrating a whole variety of ways in which research and politics interact with each other. In Chapter 5 we learn about the role of government and private industry in the development of bleaching. In Chapter 8 ethical debates and public reactions influence the course of chemical-weapons research. In Chapter 9 research on the treatment of influenza is driven directly by political and military wishful-thinking. In Chapter 10 researchers respond to wartime politics, in the First World War and the Vietnam War. In Chapter 11 economic interests clash with scientific research.

Conflicting and fractured communities. Many people speak of the importance of "the scientific community" in the acceptance and rejection of scientific ideas. However, there is rarely such a unified "scientific community" adjudicating debates. First of all, we see communities representing different disciplines contradicting and competing with each other. In Chapter 4 we see particle physicists clashing with solar physicists; in Chapter 6, physicians with chemists. More subtly, we also see fractured communities: different groups of researchers confronting each other even within the same field of study. In Chapter 9, there is a conflict between military physicians and the civilian medical establishment; similarly in Chapter 10, governmental and civil scientists vie with each other on the subject of the effect of herbicides on people; in Chapter 11, proto-environmentalist scientists are pitted against scientists representing the chemical industry. In Chapter 2 we see that even the small and tight community of "Lavoisierian" chemists was not so homogeneous in its views on Lavoisier's theory of acids.

Strategies for winning debates and commanding agreement. Many of the episodes we discuss are also interesting because they reveal various important rhetorical strategies at work in apparently factual debates. In Chapters 10 and 11, direct challenges are made to established opinion, through non-traditional media for scientific debates (public inquiries, and a popular book). In Chapter 9, we have a case of publicity stunts using the political elite and the mass media in order to boost the credibility of a new medical treatment; in Chapter 6 there are high-profile experimental trials, though these were not as nakedly political. In Chapter 2 we witness subtler methods of creating definitions of terms that conveniently suit one's theoretical arguments, and highlighting certain analogies with rhetorical force.

In the Epilogue, Hasok Chang recounts the story of the radical educational initiative that produced this book. Despite many recent efforts at reform, our educational systems still tend to be based on the notion that students are there to be trained by passively acquiring knowledge that already exists, before they can produce original work. In contrast, we believe that the processes of learning and knowledge-production can be soldered into one at an early stage. Even pioneering programmes of undergraduate research tend to make it a preserve of the best and the brightest. In our project we have made original research a routine part of an ordinary undergraduate programme, from which any competent and hard-working student can benefit. This has been made possible by the mechanism of inheritance, in which successive groups of students gradually expanded and improved on a common body of work. In addition, we strongly encouraged the students to form a community of researchers, also connecting up directly with the wider professional research community. Our project at University College London is at the forefront of the general movements for undergraduate research and research–teaching integration. We hope that this book will demonstrate clearly the feasibility and desirability of research-based instruction. Its quality and accessibility will make it an ideal showcase to encourage students and teachers in numerous other institutions to take up similar challenges.

Following the extraordinary life of chlorine has given us the pleasure of making numerous connections between various topics and academic disciplines that are usually kept quite separate. This book is a work of history of science above all, but we believe that various parts of the book will be of interest to historians of technology, medicine and war as well, and also to philosophers and sociologists. Finally, it is important to mention that we have done our utmost to make our discussions accessible to students and general readers who are interested in science, technology and medicine — both their epistemic grounding and their functioning in society. In short, we present this book to all readers interested in science, its nature, its history and its relevance in human life.