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Characters in Chemistry: A Celebration of the Humanity of Chemistry

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In Characters in Chemistry: A Celebration of the Humanity of Chemistry; Patterson, G., et al.;
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Foreword

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Before agreeing to publish a book, the proposed table of contents is reviewed for appropriate and comprehensive coverage and for interest to the audience. Some papers may be excluded to better focus the book; others may be added to provide comprehensiveness. When appropriate, overview or introductory chapters are added. Drafts of chapters are peer-reviewed prior to final acceptance or rejection, and manuscripts are prepared in camera-ready format.

As a rule, only original research papers and original review papers are included in the volumes. Verbatim reproductions of previous published papers are not accepted.

ACS Books Department

Preface

One of the recurring ideas at Bolton Society meetings over the last decade was a symposium on Characters in Chemistry. Jack Stocker and Jim Bohning were avid supporters of such an event. While neither of them lived to experience the symposium in person, they were definitely present in spirit. As the Chief Bibliophile, Gary Patterson agreed to organize such a symposium in 2012 and set out to recruit an international group of historians of chemistry known for their interest in characters (Chapter 1). The present volume is the written record of this event.

William Jensen has established a long record of outstanding contributions to the biography of chemists. As the curator of the Ralph Oesper Collection in the History of Chemistry at the University of Cincinnati, he has access to a wealth of original material, including books, pictures and ephemera. One of the richest mines in the collection contains material on Robert Bunsen (1811–1899). The article is lavishly illustrated (Chapter 2). Bunsen was a favorite subject for Oesper himself, and his collection reflects this focus. Bunsen was even famous enough to inspire caricatures. This paper, which was read first on the program, set a fine standard for quality and humor.

Another well-established biographer is the Head of the Society for the History of Alchemy and Chymistry, Robert G. W. Anderson. One of the most interesting early figures in the history of Scottish chemistry was Joseph Black (1728–1799) of Edinburgh University. Recent research into the letters of Joseph Black has revealed the extent to which he was deeply connected to Scottish Enlightenment society. In addition to the local thinkers, such as David Hume, Black was in correspondence with Montesquieu, a family friend of his father. Another friend was James Watt! Black's life as a teacher of Chemistry is extensively reviewed. He was also heavily involved in the development of Scottish industry. The presentation of Joseph Black as a fully human character adds significantly to our understanding of this Scottish pioneer of chemistry. (Chapter 3).

Alan Rocke is well-known for his biographies of Kolbe and Wurtz. In Chapter 4, he features English chemist: John Dalton. While every chemist recognizes Dalton as the father of the atomic theory, Rocke presents him in his social context as a Quaker rustic from Manchester. Unlike his younger contemporary, Humphry Davy, Dalton was simple in his manners, simple in the living style, and preferred Manchester to London. Dalton looked back to Newton, while Davy was taken by 19th century romantic idealism. They did interact strongly and continuously throughout the period 1803–1829, when Davy died. Davy's attempt to insult Dalton during his presentation of the 1826 Royal Medal of Science at the Royal Society was largely unsuccessful.

Cathy Cobb is the author of the most entertaining book on the history of physical chemists: "Magick, Mayhem, and Mavericks" (Chapter 5). For this symposium she chose a historical character of great notoriety: Lucretia Borgia (1480–1519). Borgia was well-born, well-bred and well-educated. She held high positions in the Vatican administration, and was highly admired by all in Rome (both dressed and undressed). She was a skilled chemical practitioner, but the story of her use of poison awaits. Another Renaissance woman of note was Caterina de Medici (1519–1589). She was an adept, but chose personal beauty as her philosopher's stone. Another famous Caterina (Sforza, 1463–1509) was called a virago. While living well before the age of the Ionists, these women were worthy of consideration by Dr. Cobb.

One of the most famous chemical caricatures of all time is of William Crookes (1832–1919), holding his famous "tube" and dressed too well to be anywhere near a laboratory. The current biographer of Crookes, William Brock of Leicester, kept the party going with many tales and pictures of Crookes (Chapter 6). Crookes made contributions to many areas of science, but his love was apparent in his own weekly Journal, "Chemical News". In the finest tradition of the Royal Institution, he presented many famous lectures there. He was a prolific author and a great analytical chemist. All the world was his province, and he studied more than just matter. Like Rayleigh after him, he was willing to investigate anything that could be observed. He observed several infamous "mediums." While he eventually concluded that no human possessed "spiritual" powers that could influence material systems, he did invent devices that used temperature gradients to produce motion. Of even more interest, he perfected vacuum pumps that could achieve truly low pressures. These experiments made possible the study of "cathode rays." Our picture of Victorian English science is enriched by the alchemy of Crookes.

Soon after Priestley established that there were many different kinds of gases, Humphry Davy devoted himself to the study of pneumatic chemistry at the Beddoes Pneumatic Institution. Seth Rasmussen presents the life and follies of Davy from his humble roots to his lofty station in English society (Chapter 7). Davy's early success led to his appointment at the Royal Institution and a career as the greatest public lecturer of his age. His public experimentation with nitrous oxide is one of the most enduring images of early 19th century English society. What is less well known is how close Davy came to dying from his initial experiments. The tradition of scientists testing things on themselves has produced both triumphs and tragedies.

Characters do not need to be historical to be influential in human affairs. Carmen Giunta surveys the characters found in English literature that were chemists and "characters". Carmen pays homage to the historian Ian Rae who collected books and stories where chemists appear as plot devices or even major characters. Our own Jack Stocker published an ACS volume on chemistry in science fiction (*1*). The main focus of Chapter 8 is on fiction where the primary character is a chemist. A fictional account of Joseph Priestley was published as *The Crucible* (1954). A fascinating fictional account of a chemical troika appeared as *The Holland Sisters* (2001). They married three of the most famous English chemists of the 19th century. Another chemical threesome appears as *The*

Brothers Carburi (2001). A chilling tale is told of *Harry Gold* (2000). A warm but disturbing tale is found in *The Story of Blanche and Marie* (2004). A little known side of Marie Curie is revealed, as well as the celebrated Langevin affair. While the biographical material about Chaim Weizmann may be vaguely referential, the tale *The Sun Chemist* (1976) is a fictional account of the development of biofuels and the corporate attempts to suppress them. Historical fiction based on Isaac Newton has appeared in the works of Neal Stephenson. This trilogy includes *Quicksilver* (2003), *The Confusion* (2004), and *The System of the World* (2004). Chemists are all humans and the human story can be told in fiction, both fantasy and historically motivated.

David Lewis is the leading adept of the resurrection of dead Russian chemists. His subject in Chapter 9 is Yegor Yegorovich Vagner (1849–1903). He was part of the famous Kazan mafia and learned his craft as a thespian chemist there. As a chemist he was especially brilliant in his inferences of the structures of organic molecules, long before modern structural methods. Zaitsev (1841–1910) realized his potential and arranged for him to spend time at St. Petersburg University with Butlerov (1828–1886). Another collaborator in St. Petersburg was Menshutkin (1842–1907). Vagner's first real position was at Novo-Aleksandriya Institute of Agriculture and Forestry (1882). By 1886 he was installed as Professor of Organic Chemistry at Warsaw Imperial University. After obtaining the prestigious Dr. Khim. degree, he was promoted to the Warsaw Technological Institute in 1889. While competing against the best organic chemists in the world, Vagner correctly inferred the structure of pinene. One of the secrets of his success was his ability to focus for long hours on a tough problem. He was a great lecturer and his students often ended his classes with rounds of applause (unheard of today). He was much beloved by the Russian chemical community and one of the best-known Russian chemists who emigrated to America, Ipatieff (1867–1952), remembered him as the "life of the party" at scientific meetings. Perhaps Vagner was even up to the standards of David Lewis!

Russians are not the only characters in the history of chemistry. Hungary has also produced its share of interesting people. The leading historian of Hungarian science, Istvan Hargittai, and his son, Balazs Hargittai, brought this subject to the party with a paper on the "Martians of Chemistry" (Chapter 10). While von Karman, von Neumann, Szilard, Wigner and Teller are perhaps best known for their government work in the United States, they were all Hungarians who had backgrounds in chemistry or chemical engineering. These five legendary humans were also larger than life figures, both in Europe and the United States. They exemplified the designation as true Characters in Chemistry.

History is still being made, and some living chemists are already legendary characters (Chapter 11). James Traynham, a former chairman of HIST and a regular interviewer for the oral history program at the chemical Heritage Foundation, presented a paper on George Rosenkranz (1916–), best known as the retired Director of Syntex in Mexico City. He was born in Hungary, but the changing political situation in the 1930s led him to attend college at the ETH in Zurich. He was an especially avid student of chemistry and amazed the notorious Leopold Ruzicka with his knowledge and understanding. He was enterprising in the extreme, a useful skill for a Jewish student without a source of funds from

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“back home.” His pilgrimage to the Americas landed him in Cuba in 1941 with no easy way to leave. He went to work for a pharmaceutical company and made the most of his opportunities. He also had a clear eye for feminine beauty and convinced his beloved to marry him and emigrate to Mexico City to work for Syntex. More than once in his life, his love and talent for bridge has served him well. When he started at Syntex in 1945, the company was deeply in debt; when he sold the company to Roche in 1995, it fetched $5.3 billion. The full story is archived at the Chemical Heritage Foundation as a bound oral history (*2*).

The final paper presents some early work from the forthcoming biography of Paul John Flory (*3*) (Chapter 12). Paul Flory received the Nobel Prize in Chemistry in 1974 for his pioneering work in the foundations of polymer science. He was fortunate to land a job a DuPont working with Wallace Carothers, the foremost synthetic polymer chemist in 1934. Flory, like Carothers, was fully committed to fundamental science, even if it was of use to industry! When Carothers committed suicide, Flory commenced an odyssey that included stops at the University of Cincinnati, Esso Laboratories, and the Goodyear Tire and Rubber Company. He was one of the knights of the Rubber Roundtable during World War II. Wherever he went, he made good friends for life, and real enemies. He remarked upon leaving Goodyear that he was “tired of casting synthetic pearls before real swine!” His impressive scientific productivity and synoptic knowledge of polymer science led Peter Debye to arrange for Flory to come to Cornell in 1948. He met more good friends, did a lot more great science, and published the monumental volume, *Principles of Polymer Science* (1953). After a sabbatical at the University of Manchester, Paul Flory became the Director of the Mellon Institute for Industrial Research in Pittsburgh. This detour was soon over and he moved to Stanford University, where he finished his career. After his Nobel Prize, he devoted his passion and energy to human rights causes. He was the principal human rights advocate in the National Academy of Sciences. He was chosen by the United States government to be on the team that attended the review of the Helsinki Accords. He was fearless in these situations and produced real results for dozens of individual scientists behind the Iron Curtain. He was especially well-known for his work on behalf of Sakharov, Orlov and Scharansky. His human rights archives in the Hoover Institution at Stanford are enormous, consistent with the major role he played from 1974 to his death in 1985.

The day-long symposium concluded with a dinner at the Chemical Heritage Foundation. The “characters” in this volume were celebrated in the building where all characters in chemistry are feted.

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Chapter 1

Introduction: The Humanity of Chemistry

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It is easy for society to maintain the stereotypical view of science — the sterile, cold image of laboratory activities being carried out by highly educated, but passionless, white lab-coated minions. To counter this, it is important for those in science to reveal and communicate the humanity of chemistry and the other sciences. This introductory chapter will present the benefits and potential impact of humanizing science, as well as the place of the scientific biography in these efforts.

Humanizing Science

The stereotypical view of science held by much of society is the sterile, cold image of laboratory activities being carried out by highly educated, but passionless, white lab-coated men and women. Unfortunately, this view is rarely countered and the humanity of science is often overlooked or poorly communicated. In fact, new discoveries and other discussions of science in the media usually include little to nothing about the personal side of those repsonsible, other than perhaps a name and affiliation. To add to the problem, things are usually not any better within our own science courses (*1–7*). As stated by chemical historian Ralph E. Oesper (1886–1977) (Figure 1) in his book *The Human Side of Scientists* (*1*):

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> It is now common practice to employ the names of scientific personalities only as convenient handles when referring to theories, laws, reactions, types of equipment, names of compounds, etc. The teachers in general and hence their students know little if anything about the actual individuals whose work they discuss...

Figure 1. Ralph E. Oesper (1886–1977). (Courtesy of the Oesper Collections: University of Cincinnati).

Of course, Oesper goes on to state that the elimination of historical elements from science courses is, in most cases, due to the explosive growth of new material to be covered (*1*). As a consequence, it is difficult to fit historical topics and personal stories into the topic loads of current science classes and are thus often the first topics to be cut from a course curriculum (*2–4*). This is especially unfortunate as students, and society in general, are typically more receptive to the subject when they can visualize people in science. In fact, including the history of chemistry, with its emphasis on people and society, can be an excellent tool to place chemistry in perspective as a human activity (*2*, *8*). The strength of this human component is exemplified by the words of chemical educator and historian Bernard Jaffe (1896–1986) (*9*):

> Inextricably tied to these world-shaking advances was an even greater story — the human one — the saga of men groping for causes and struggling to frame laws; of men leading intellectual revolutions and fighting decisive battles in laboratories. Here was meaning, light, inspiration, life.

Of course, Jaffe's choice of words to describe the work of scientists as a heroic intellectual enterprise seem to limit that enterprise to men (*2*). Presenting science as a human endeavor, however, can correctly illustrate the human diversity of scientists and the fully international character of science (*9*, *10*). This can thus undermine the tendency of many students to view science as a product of men from the U.S. and Europe (*2*). At the same time, intellectual honesty requires us to acknowledge the historical reality that social factors of the past have limited the participation of women and of many non-European ethnic groups in science, and thus many works of the history of chemistry do in fact emphasize the achievements of men of European descent (*2*). The past effects of these limitations still influence the present and selecting examples of women and other underrepresented groups who made significant contributions to chemistry despite disadvantages (*11*) can illustrate important aspects of the human side of science (*2*). In this way, the Eurocentric male view can be dispelled as students come to understand that no gender, country or culture has a monopoly on discovery (*8*) and that many of chemistry's beginnings originated in the Middle East, Egypt, and Asia (*2*).

One of the concerns expressed about revealing the humanity of chemistry, is that it may turn impressionable students away from the science by letting them see that chemists do not always behave as rational, open-minded investigators who proceed logically, methodically, and unselfishly toward the truth (*10*, *12*). In particular, by taking an accurate and honest look at some of the most revered figures in chemistry, this may somehow tarnish their reputations and reduce students' admiration for these scientists and their accomplishments (*12*, *13*). However, one could argue that this is just as valid a reason to include the full, honest truth in history. As educators, it is becoming more and more common to witness students begin their study of science with the attitude that it is just not possible for them to master the subject. Such students feel that such accomplishments are far too hard for a "normal" student such as themselves and that to succeed in science requires exceptional intellectual abilities (*2*). By recognizing that these great figures of chemistry made mistakes and were human beings with strengths and weaknesses not all that different from themselves, it can give students the confidence to try, rather than to give up before they have started (*2*, *6*, *7*, *14*). A full historical approach that includes all the error, approximation, and human foibles, allows students to witness the reality of science at work (*13*). Here students can see that one does not need to have an extraordinarily high IQ to be a successful scientist (*14*). At the same time, while intellect and education can be important, so too are enthusiasm, optimism, an appetite for hard work, as well as a bit of luck (*2*, *14*). For such students, a full historical account can illustrate the number of times great discoveries have been made by those with average abilities, poor training, or faulty logic and can just as importantly show that such discoveries are rarely made by one scientist alone, but that such accomplishments were also dependent on the work, theories, and insight of other contributing scientists (*2*). In the same way, revealing the humanity of chemistry recognizes the place of imagination in science and gives students better recognition of their own creative abilities as they learn that intuition, as well as logic, is a legitimate approach to problem-solving (*13*, *15*).

In the end, it is simply in our best interest to take the time to remind students and society alike that scientists, even noted leaders in the field, are human (*1*) and that science itself is a critical aspect of humanity. As stated by chemist George W. Gray (*9*):

> The idea that science is something outside of humanity, or is of a lower order of human interest than poetry, painting, architecture, or the arts, is one of the oddest quirks of casuistry.

The Biographical Approach

One of the easiest methods to convey science as a human endeavor is through the biographical approach (*10*). The historian Thomas Carlyle goes even further to state, "*History is the essence of innumerable biographies.*" (*5*, *6*). The benefits of a biographical approach in teaching chemistry and communicating the essense of the science have been widely recognized. This is exemplified once again by the words of Jaffe (*5*, *6*):

> An effective way to teach the methods of science is to show how our great scientists reached their goals and how their minds worked in the process.

The biography has been said to be the most popular category of non-fiction books (*16*) and can be one of the most inspiring teaching tools for students (*6*). After all, people enjoy a good story (*9*). Even among practicing scientists themselves, stories about their scientific colleagues have always been popular, particularly stories that have a humorous twist. Students and teachers of chemistry, and chemists in general, are literally starved for stories and anecdotes about the figures whose names they use so glibly in reference to well-established concepts, discoveries, and laws. In fact, most scientists, if given a chance, would be glad to be shown that those of their profession are really human and in many cases even humorous (*1*).

In terms of historical contributions, biographies of scientific figures continue to contribute to our understanding of past events and those that participated in them. Even for those prominent chemists that have already been a major focus of study, it has been stated that a final, definitive biography can never be written (*5*, *6*, *17*). Each new study can always offer additional context and new insight via a fresh point of view, if not specific new facts or data. Even in terms of the data itself, information dismissed by one era as too specialized or obscure may appear to a later era to be proper material for detailed study (*17*).

Studies of chemists of lesser prominence can also be of significant impact. Biographies of such figures may be the only one in the literature and thus become a definitive contribution (*5*, *6*). Social historians and sociologists have even challenged historians to move beyond the frequently targeted heroic figures and write about ordinary scientists and to study the technicians and instrument makers who do much of the supporting work of science (*16*). In the process, such new biographies can bring to light significant contributions that have thus far been overlooked, or have at least not been well communicated.

In the end, science is very much a human endeavor and is carried out by a wide variety of participants, some of whom fit the stereotypical view of the scientist, but there are many, many more who definitely do not. Either way, however, chemistry has always been populated with an entertaining cast of 'characters' and will, in all likelihood, continue to generate future 'characters' as well.

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Chapter 2

Robert Bunsen's Sweet Tooth

Bunseniana in the Oesper Collections

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The 19th-century German chemist, Robert Bunsen, certainly qualifies as a "chemical character" and is the subject of many surviving anecdotes, collectively known as "Bunseniana." This paper will review many of these anecdotes and their historical sources based on the rich resources of the Oesper Collections in the History of Chemistry of the University of Cincinnati, including several unique, one-of-a-kind, items inherited from former students of Bunsen.

What is a Chemical Character?

As some members of this audience are aware, Ralph Edward Oesper (Figure 1) was the recipient in 1956 of this Division's first Dexter Award for Outstanding Achievement in the History of Chemistry (*1*). But perhaps fewer in the audience are aware of the reasons for the award, which focused on Oesper's extensive contributions to the field of chemical biography (*2*). Indeed, the many photographs, portraits, and biographical memoirs which he collected over the years in pursuit of this interest form the nucleus of the current Oesper Collections in the History of Chemistry at the University of Cincinnati, as well as the monthly frontis-pieces for nearly 20 years of the *Journal of Chemical Education* (*3*).

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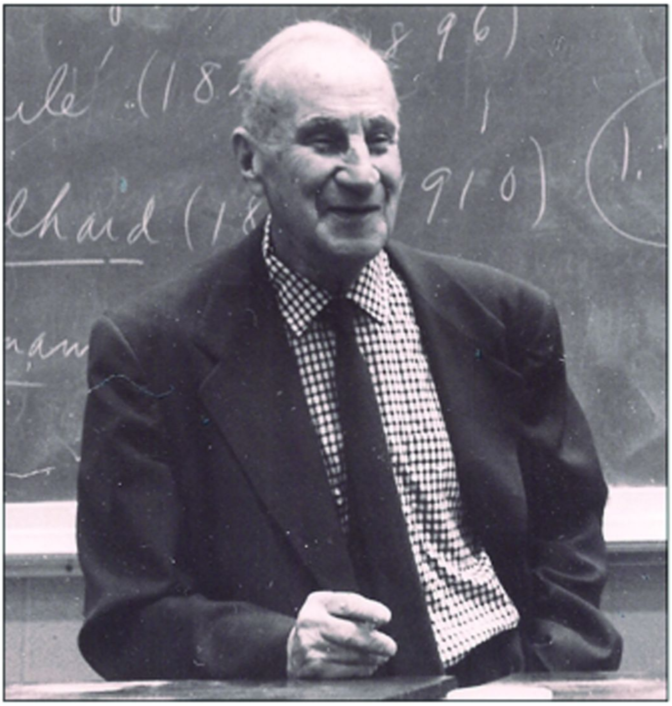


Figure 1. Ralph Edward Oesper (1886−1977). Courtesy of the Oesper Collections.

However, Oesper wasn't just interested in chemical biography, he was also interested – in keeping with the theme of this symposium – in the biographies of "chemical characters," taking the term "character" to mean one whose biography may be easily written in accord with the advice first given by the British humorist, Edmund Clerihew Bentley, in 1905 (*4*):

> In all works of a biographical character it is important to make copious reference to as many as possible of the generally recognized virtues, vices, good points, foibles, peculiarities, tricks, characteristics, little weaknesses, traits, imperfections, fads, idiosyncrasies, singularities, morbid symptoms, oddities, faults, and regrettable propensities.

As suggested by this admonition, we might define a "character" as a person concerning whom many anecdotes – humorous or serious, real or fictitious – have survived and Oesper, as it turns out, was not only a collector and writer of biographies, but also a connoisseur of the art of the anecdote. This is revealed in a small collection of German-language books dealing with biographical anecdotes of famous scientists, which Oesper collected over the years (*5*). At least one of these – a small volume by Josef Hauser entitled (in translation) *What Can't* *be Found in the Annalen* – dealt exclusively with chemical anecdotes and was sufficiently popular to have passed through at least six editions (*6*). This interest culminated in Oesper's own book, *The Human Side of Scientists*, published in 1975 when he was 89 years old, and which, despite its title, also dealt almost exclusively with chemical anecdotes (*7*).

Robert Wilhelm Bunsen

If one were to single out which chemist, among the many Oesper wrote about during his life, was his favorite, the honor would almost certainly go to the German chemist, Robert Wilhelm Bunsen (Figure 2). Indeed, one of the first biographical studies written by Oesper was on Bunsen and appeared in the April 1927 issue of the *Journal of Chemical Education* (*8*). This was followed by a second article in 1941 on Bunsen's participation in 1846 in an expedition sent to investigate the volcanoes of Iceland (*9*), and by yet a third in 1955 dealing with Bunsen's transfer from the Cassel Gewerbeschule, where he began his teaching career in 1836, to the University of Marburg in 1839, where he remained until his move to the University of Breslau in 1851, and finally to the University of Heidelberg the next year (*10*).

Figure 2. Robert Wilhelm Bunsen (1811−1899). Courtesy of the Oesper Collections.

This latter article was coauthored by the German chemist and historian, Georg Lockemann, who had published a book-length biography of Bunsen in 1949 (*11*) and had inspired Oesper to translate it into English, though Oesper never succeeded in finding a publisher and the original manuscript of the translation still languishes in our files. Indeed, though a few inferior German biographies have appeared since (*12*), and there are many chapter-length accounts in both German and English (*13*), Lockemann's biography is still, to the best of my knowledge, the most comprehensive available in any language.

In his pursuit of Bunsen, Oesper also rapidly acquired copies of virtually every printed book related to Bunsen's research and teaching activities, including the installments of Ostwald's series, *Klassiker der Exakten Wissenschaften*, dealing with Bunsen's classic work on organoarsenic compounds (*14*), on photochemistry (*15*), and on spectrum analysis (*16*); the definitive three-volume 1904 set of Bunsen's collected papers (*17*); copies of his 1857 monograph on gas analysis (*18*, *19*), and a wonderful illustrated history of the chemical laboratory at Heidelberg (*20*). Since Oesper's death, we have continued this tradition by also acquiring copies of more recently published collections of Bunsen's letters (*21*, *22*).

Bunseniana

One of the reasons Oesper was so attracted to Bunsen was because there is little doubt that Bunsen was an example *par excellence* of a chemical "character" in the sense defined earlier, and Oesper did not overlook this aspect in his collecting activities. Indeed, one of our prize possessions is a small booklet of Bunsen anecdotes published anonymously by Adolf Mayer in 1904 under the title (in rough translation) of *Bunseniana: A Collection of Humorous Stories from the Life of Robert Bunsen Presented by One Who Witnessed Many and Drew the Rest from Reputable Sources* (*23*). Many of these anecdotes were incorporated in Oesper's 1927 account of Bunsen's life.

Use of the term "Bunseniana" as a convenient descriptor for humorous Bunsen anecdotes seems to have caught on among his former students after his death and was used by the British chemist, Henry Enfield Roscoe, in his Bunsen Memorial Lecture of 1900 before the British Chemical Society (*13*), and also as a chapter title in his own autobiography of 1906 in which he recounted the incidents which had occurred during a visit that Bunsen, and his well-known colleague and collaborator, the German physicist, Gustav Kirchhoff, had made to Manchester in 1862 (*24*). Roscoe had spent the years 1853−1855 in Bunsen's laboratory at Heidelberg working with him on the laws of photochemistry (*14*), and had continued the practice during summer breaks and long vacations until his marriage in 1863. One of the mementos of the 1862 visit was a famous set of group photographs (Figures 3 and 4) taken in Manchester and they are now among the best which show Bunsen and Kirchhoff together. During their visit Roscoe also arranged for the two German scientists to visit the London Exhibition and to meet a wide range of British scientists, including Wheatstone, Joule, and an aged Faraday.

Figure 3. The well-known group photo of Gustav Kirchhoff (left), Bunsen (seated), and Henry Enfield Roscoe (right) taken during a visit to Manchester in 1862. Courtesy of the Oesper Collections.

As Roscoe noted, Bunsen had a “keen” sense of humor. At one dinner party an elderly lady, on being introduced, mistook him for the famous German diplomat and scholar, Baron Christian Charles Josias von Bunsen, who had died in 1860. “Pray sir.” asked the lady, “have you not yet finished your great work on God and History?” “Alas no, madam,” replied Bunsen, “my untimely death prevented me from completing my task.” This sense of humor was also shared by Kirchhoff and the two would often tease one another. Thus on being invited by Charles Arnold, the Head Master of the famous Rugby School, to attend Sunday services in the school’s chapel in order to witness its famous boy’s choir, both Bunsen and Kirchhoff, neither of whom were particularly religious, “expressed great unwillingness to do so, Bunsen saying that he had not been inside a church for seven years, the last time being at the marriage of his niece.” Hence Roscoe’s great surprise when Bunsen appeared on Sunday morning ready for church and dressed “in a costume he very seldom indulged in – a tailcoat, white tie, etc., etc., and on his hands a large pair of white kid gloves.” Continued Roscoe (*24*):

> The sight in the chapel at Rugby of all the boys in surplices is certainly a very interesting one, and my German friends were much impressed, Bunsen saying to Kirchhoff afterwards, “Do you know, I really felt quite devout.” “Oh nonsense,” retorted Kirchhoff, “you were only sleepy.”

Figure 4. A second group photo taken during the Manchester visit of 1862, this time showing only Kirchhoff and Bunsen. Courtesy of the Oesper Collections.

Caricatures

If the existence of large numbers of anecdotes is a written indication that we are dealing with a “character”, then graphic evidence for the same conclusion may be found in the survival of period caricatures and cartoons. Here Oesper’s collaboration (*10*) with Lockemann comes into play as it uncovered one of the few known examples of a period cartoon of Bunsen – albeit one done quite early in his career to commemorate his move in 1839 from Cassel to the University of Marburg. It depicts him as a tall, lanky young man in a stovepipe hat smoking a clay pipe and reading a book while sitting astride a cart full of chemical apparatus (Figure 5). Being accustomed to images of Bunsen showing him in middle age and dating from his Heidelberg period, this may, at first glance, seem like a poor caricature. However, an examination of one of the few formal portraits of a young Bunsen from his Marburg days (Figure 6) quickly reveals that it is in fact quite accurate. A modern caricature of our more familiar image of Bunsen (Figure 7) is shown in Figure 8.

Figure 5. A period caricature of Bunsen commemorating his move from Cassel to Marburg in 1839. Courtesy of the Oesper Collections.

Figure 6. A portrait of Bunsen as a young professor at the University of Marburg. Courtesy of the Oesper Collections.

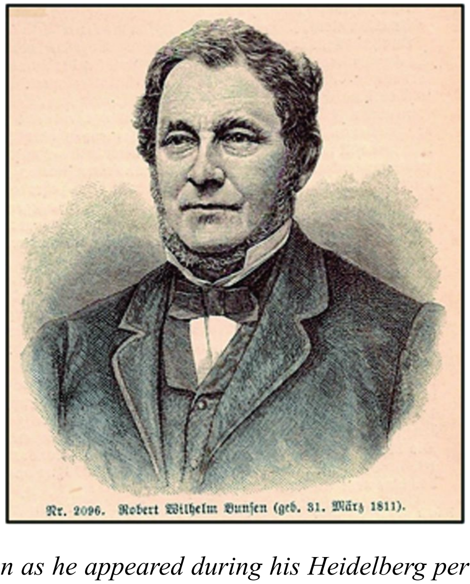


Figure 7. Bunsen as he appeared during his Heidelberg period. Courtesy of the Oesper Collections

Figure 8. A modern caricature of Bunsen during his Heidelberg period. Courtesy of the Oesper Collections.

Work Habits

Many Bunsen commentators have noted his lack of interest in chemical theory and his almost total devotion to experimental work. As a consequence he remained active in the laboratory his entire career and many surviving Bunsen anecdotes center on this activity. He had in fact visited Manchester for the first time in 1844, when he was hosted by Lyon Playfair, and had spent his time analyzing gases from blast furnaces in preparation for his monograph of 1857 on this subject, which was translated into English the same year by Roscoe (*18*). This work led to the discovery that cyanogen gas was sometimes formed in blast furnaces – a discovery which almost cost Bunsen his life when he was overwhelmed by the fumes that came rushing out of a tube that he had just tapped into the bottom of a furnace. (*25*).

Nor was this the first or last time that Bunsen would have a close brush with death. While working on organoarsenic compounds at Cassel, he had a tube of cacodyl or dimethylarsine cyanide explode, blinding him in one eye and putting him in bed for several weeks with a near fatal dose of arsenic poisoning (*13*). Later, at Heidelberg, he almost lost the sight in the other eye from an explosion which occurred when he incautiously held a lit taper over a mixture of freshly reduced platinum metals containing a large quantity of occluded hydrogen gas. What happened next has been described by the British chemist, Thomas Edward Thorpe, who had come to Heidelberg to work with Bunsen in 1867 (*24*):

> The next morning the rumor ran around town that Bunsen was blinded, and the Wredeplatz was packed with students and burghers anxiously inquiring if the news were true. No certain information could be gained and the crowd swayed backwards and forwards throughout the day waiting for tidings. It was late afternoon before a proper examination could be made, when it was discovered the eye was safe. Friedrich, the surgeon, promptly stepped out onto the balcony to announce the fact, when the air was simply rent with huzzas, caps went flying up, men embraced each other, women wept. Such a scene I never witnessed before, nor have I seen the like of it since. If the cheers reached the darkened room in which the dear old man was sitting – as indeed they must, for the noise was terrific – he must have gathered how strong was the hold he had on the affections of the whole place.

Bunsen was particularly proud of the fact that, with his large thumbs, he could seal the end of a gas eudiometry tube and insert it into a pneumatic trough in a single movement, and he would later often use thumb size as a criterion for evaluating the probable laboratory skills of his students. Again in the words of Thorpe (*24*):

> The day came when I was to be indoctrinated into the art and mystery of gasometric analysis – Bunsen's gasometric analysis – and by Bunsen himself. It was a red-letter day, and I determined to mark it by purchasing the finest eudiometer Desaga stocked. With his help I picked out the longest, straightest, and widest in the shop and returned in triumph with it to the laboratory. As I passed through the swing door, I came upon Bunsen, who asked me what I had got. I showed him the instrument and it met with his approval, but, taking my hand, he showed me to his own amusement, but to my consternation and disgust, that my thumb could not possibly close it. He then proved to me with what ease he himself could close it; his right thumb indeed, by constant use, was like a pad, and to my astonishment much larger and wider than that of his left hand. I am afraid I must have looked – as I felt – rather foolish and chap fallen, as I gazed on my incompetent digit, But he sought to cheer me with the remark: "Sie mussen recht viel arbeiten und es wird grosser werden." I regret to say, however, that I never succeeded in closing that eudiometer as Desaga sold it to me.

Bunsen's insistence on the importance of detail and accuracy when performing chemical analyses is revealed in the famous anecdote of the fly. One day the students in the adjoining teaching laboratory heard a loud ruckus coming from Bunsen's private laboratory. On investigating, they found Bunsen madly leaping from bench top to bench top in pursuit of a fly. It seems that he had been performing an analysis for beryllium, and returning to his filtration stand after going in search of his wash bottle, had discovered, much to his horror, a fly sitting on the edge of the funnel with its proboscis stuck in the sticky, gelatinous precipitate of beryllium dihydroxide that was being filtered. The fly immediately took off with some of Bunsen's precious precipitate still stuck to its proboscis. The students gleefully joined in the pursuit and, when the fly was finally caught, Bunsen (*7*):

> ... killed it between his thumb and index finger, taking care not to touch the proboscis, he then placed the carcass in a weighed platinum crucible and carefully cremated the remains. The resultant ash was treated with a drop of strong hydrochloric acid and the solution then treated with ammonia water. After evaporation and ignition, the crucible contained about 0.1 mg of BeO. This amount was then added to the weight of the main ignition residue and an excellent result was thus obtained for the analysis.

To the human palate beryllium compounds taste sweet, whence the original name of glucinium for the element, and it is interesting to speculate whether a similar sweetness response was the cause of the fly's initial attraction to the precipitate.

Bunsen's ability to become totally absorbed in his laboratory work also led to an incident that would have lasting consequences for his future life style. While still a professor at Marburg it was rumored that he had proposed marriage to a young woman and had been accepted. However, soon after, he became so absorbed in his work on organoarsenic compounds that he failed to materialize for several weeks. When he finally emerged from the laboratory, he could remember his intention of proposing but could no longer remember whether he actually had, so to be on the safe side he made another appearance at the young woman's home and repeated his proposition. She, however, was so outraged at his prolonged absence and inability to remember such an important event that she threw him out (*8*).

As a consequence, he remained a bachelor his entire life and displayed all of the eccentricities that generally accompany such a fate – eccentricities that only increased with age. When he accepted the appointment at Heidelberg, he was promised a new laboratory. This was completed in 1855 (Figure 9) and came with an attached *Wohnung* or official residence (Figure 10). This residence was rather large for Bunsen's simple personal needs and so he left several of the rooms empty, and even used one of them to deposit his unwanted mail in a large heap in the center of the floor (*8*). By the time of his retirement at age 78 in 1889, he was looking rather tattered around the edges (Figure 11). When Emil Fischer was being interviewed as his possible successor, Bunsen took both the candidate and his wife to lunch at his favorite restaurant, which was located in the nearby Grand Hotel (*7*):

As they sat down, Frau Fischer said to the aged celebrity: "Professor Bunsen, where is your necktie?" With a sweet smile, Bunsen reached into his vest pocket and produced a ready-made specimen that had seen better days and put it on. After they had returned home, some of the faculty wives asked Frau Fischer her impressions of the world-famous chemist. Smilingly she replied: "First I wanted to wash him and then to kiss him."

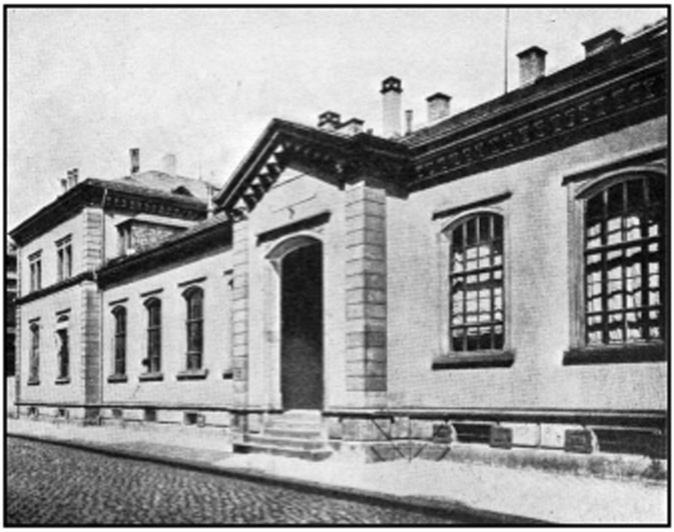


Figure 9. The front of Bunsen's new laboratory at Heidelberg which was completed in 1855. Courtesy of the Oesper Collections.

Figure 10. Bunsen's official residence at Heidelberg. The attached laboratory is to the left behind the house. Courtesy of the Oesper Collections.

Figure 11. A somewhat disheveled Bunsen in old age. Courtesy of the Oesper Collections.

By 1889 Bunsen's laboratory was nearly 35 years old and in the end, Fischer, feeling that the facilities were too outdated, turned down the appointment, which was given instead to Bunsen's former pupil and assistant, Victor Meyer.

Inventions

In his day Bunsen was as well known for his numerous improvements in standard laboratory apparatus (Table 1), as he was for his chemical discoveries, and many of these innovations still bear his name. Several of these would have made him a fortune had he chosen to patent them. This was particularly true of his carbon battery (Figure 12), which replaced the expensive platinum cathode of the standard Grove cell with an inexpensive one made of baked carbon (*27*). However, Bunsen refused to become involved in such commercial ventures and, on occasion, even expressed great distain for those who did, saying of a former student (*13*):

> I cannot make the man out. He has certainly much scientific talent and yet he thinks of nothing but money-making, and I am told that he has already amassed a large fortune. Is this not a singular case? ... Working is beautiful and rewarding, but acquisition of wealth for its own sake is disgusting.

Table 1. Bunsen's More Famous Improvements in Chemical Apparatus

Improvement	*Date*
Carbon Battery	1841
Grease-Spot Photometer	1844
Gas Burner	1857
Spectroscope	1860
Filter Pump	1868
Ice Calorimeter	1870
Vapor Calorimeter	1887

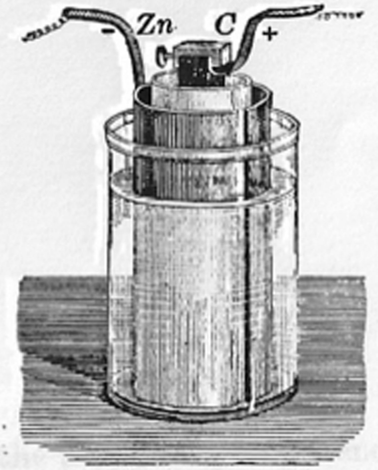


FIG. 77.—BUNSEN CELL.

Figure 12. A later commercial version of Bunsen's carbon cell. Courtesy of the Oesper Collections.

Perhaps the most famous of Bunsen's various innovations was his tubular gas burner (Figure 13), which was based on improvements made to an earlier laboratory heating device known as a gauze burner that Roscoe had brought to Heidelberg from the laboratories of University College in London (*28*). Here again was an opportunity to make money, but Bunsen left the commercial gains and patent squabbles to his machinist, Peter Desaga, who had helped with its design.

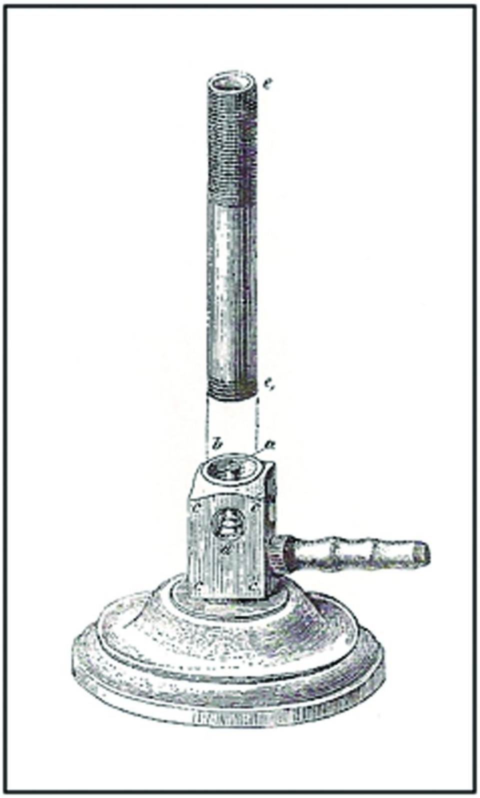


Figure 13. Bunsen's original burner of 1857. Courtesy of the Oesper Collections.

A standard lecture demonstration concerning the structure of the burner flame was to suspend the head of an unlit match inside the inner cone of the flame in order to show that it was composed of unlit gas and was relatively cool. Bunsen, however, took a more memorable approach in his own chemistry lectures (*8*):

> His large, powerful hands were covered with thick tough skin, seemingly insensitive to heat and, when lecturing to students on his well-known burner, he often amazed his audience by holding his finger in the nonluminous flame until the smell of burning flesh was distinctly perceptible. He seldom needed tongs to remove the lid from a hot crucible. Although very proud of his hands in the laboratory, he was very conscious of their size and appearance when at table with ladies and constantly drew attention to them by his efforts to keep them concealed.

There is little doubt that Bunsen's greatest contribution to chemistry came through his collaboration with Kirchhoff and their use of the spectroscope (Figure 14) as a tool for qualitative analysis, leading to their discovery of the elements cesium and rubidium in 1860 and 1861, respectively. And this, in turn, brings us to the subject of Bunsen's cigars. As may be seen from the portraits in Figures 11 and 15, Bunsen became an ardent cigar smoker in later life and, like the cigars brandished by the late G. N. Lewis, they soon became an inherent part of his public persona. But whereas Lewis favored cigars from Manila, Bunsen liked Cuban cigars, though he had to pay a premium price for them from his local tobacconist in Heidelberg. As a consequence, he was always concerned that the tobacconist was cheating him by substituting a cheaper tobacco from another source. Eventually, however, he discovered that the soil in which Cuban tobacco was grown was particularly rich in lithium and that the element collected in the tobacco leaves and could be detected spectroscopically using its characteristic red line. Thereafter, whenever he would buy a new box of Havana cigars, he would immediately head for the laboratory to confirm their authenticity by sprinkling some of the tobacco into a Bunsen burner flame and checking for the red lithium line with his spectroscope.

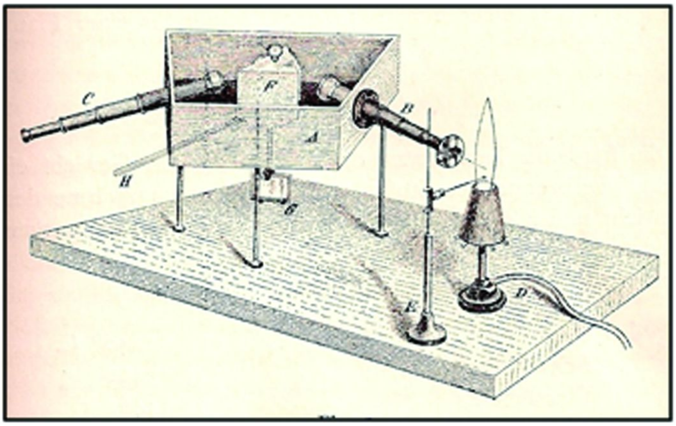


Figure 14. The original spectroscope used by Bunsen and Kirchhoff, supposedly made from one of Bunsen's cigar boxes and some old telescope parts, c. 1860. Courtesy of the Oesper Collections.

Figure 15. Bunsen in old age with his hallmark cigar. Courtesy of the Oesper Collections.

The cigars, he claimed, helped him to think and to relax (*7*):

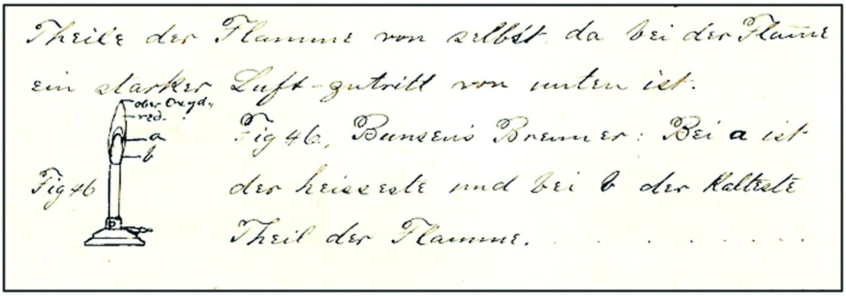
> In his younger days Bunsen liked mountain climbing, but as he grew old he evolved an unique and less strenuous system. Together with his companions he would select a peak, and then, near the starting point, find a tree that cast considerable shade. Telling the party to go on without him, he would light a cigar and, having no wife to chide him for his extravagance, would burn a hole in his handkerchief. Then he would lie down in the shade. Drawing the handkerchief over his face as protection from insects, he would insert the cigar through the hole and smoke and slumber until his companions returned.

Former Students

Ralph Oesper was only 13 years old when Bunsen died in 1899 and so could never have known him as a fellow professional. However, as pointed out in his biographical article of 1927, Oesper did have the privilege of knowing several of Bunsen's students. These included Thomas Herbert Norton, who was the second Professor of Chemistry at Cincinnati, and Alfred Springer, who was a local Cincinnati industrial chemist.

After graduating from Hamilton College, Norton (Figure 16) departed for Europe in the summer of 1873 to pursue graduate work in chemistry under Bunsen, and at least three mementos of his two-year stay at Heidelberg are still in the Oesper Collections at the University of Cincinnati (*28*). These include the textbook which he used (the 1869 edition of Adolf Strecker's *Kurzes Lehrbuch der anorganischen Chemie*), a carefully bound set of handwritten notes for Bunsen's introductory lectures on "Experimental Chemistry" (Figure 17) (*29*), and a set of framed photographs of Norton's Ph.D. committee, which consisted of Robert Bunsen and Hermann Kopp in chemistry, Gustav Kirchhoff in physics, and Johann Blum in mineralogy. On 4 March 1875 this committee granted Norton a Ph.D. *summa cum laude* (*30*). After further experience in the laboratories of August Hofmann in Berlin and Adolphe Wurtz in Paris, followed by employment as an industrial chemist at St. Denis in France, Norton accepted the position of Professor of Chemistry at the University of Cincinnati in 1883, where he remained until his resignation in 1900, several years before Oesper became a student at the University. However, he visited Cincinnati several times in later years and in this fashion became personally known to Oesper.

Figure 16. Thomas Herbert Norton (1851−1941). Courtesy of the Oesper Collections.



Theile der Flamme von selbst da bei der Flamme
ein starker Luft-zutritt von unten ist.
Fig 46. Bunsens Brenner: Bei a ist
der heisseste und bei b der kälteste
Theil der Flamme. . . . . . .

Figure 17. Drawing from Norton's handwritten notes for Bunsen's lectures for the winter semester of 1877−1878 discussing the structure of the Bunsen burner flame. Courtesy of the Oesper Collections.

The bound lecture notes also call to mind an anecdote concerning Bunsen's introductory chemistry lectures. The old lecture hall at Heidelberg (for which alas there are no surviving photos) had several support pillars situated among the seating for the students. Unlike American universities, there were no examinations or grades given for individual courses in 19th-century German universities, though the students had to present proof of lecture attendance by having the professor sign a certificate of attendance. When presented with the certificate, Bunsen would often observe that he did not recognize the student and was unsure whether he had ever been to lecture, to which the student would inevitably reply, "That is because, Herr Professor, I am the student who sits behind the pillar," whereupon Bunsen would sign the certificate, while observing with a sigh, "Alas, so many sit there" (*24*).

Alfred Springer (Figure 18), on the other hand, was born and raised in Cincinnati (*31*). Immediately after graduation from high school in 1870, at age 16, he left for Germany to study under Bunsen, receiving his Ph.D in May of 1872 at age 18. Returning to Cincinnati, he became involved in several successful businesses in collaboration with his maternal uncles, Alexander and Gustav Fries, and with several of his Fries cousins, all of whom were chemists, including a company specializing in flavoring agents and another for the manufacture of torsion balances, on which Springer held several key patents. He also played a key role in organizing the Cincinnati Chemical Society of 1880 and in its later reorganization as the Cincinnati Section of the ACS.

Among the Springer mementos in the Oesper Collections are Springer's signed copy of the Strecker textbook which he, like Norton, had used at Heidelberg, and a large collection of photos and letters provided by his granddaughter, Else Miller, who was also a chemist. These include a copy of the terse telegram that he sent to his family on receiving his doctorate (*32*):

> Heidelberg, May 4th 1872
> Raised [i.e. promoted] – a splendid examination.
> Doctor Alfred

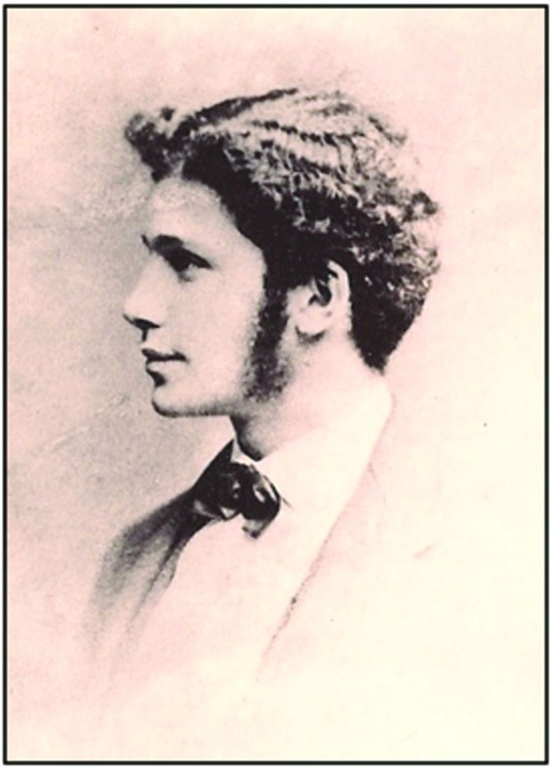


Figure 18. Alfred Springer (1855−1946) as a young student at the University of Heidelberg. Courtesy of the Oesper Collections.

as well as his mother's congratulatory reply, which began (*33*):

> My magnificent boy, My dear Doctor!

Also included is the correspondence detailing Springer's European trip of 1887 to attend the Victoria Golden Jubilee Meeting of the British Association for the Advancement of Science in Manchester, where, among others, he met Lothar Meyer and Mendeleev. While in England he also made a side trip to the continent to visit his old professors at Heidelberg, as recounted in a letter of 12 August 1887 (*34*):

> Here I am, after an interval of more than fifteen years, writing a letter in lovely old Heidelberg. All of us are as much charmed with the dear old place as I was in former years.
> ... Yesterday morning I went to Bunsen's private house and, after ringing the bell for five minutes, the servant girl opened the door and I asked for "Excellency." The girl told me he was quite sick but she would take my card up. She did so and came back with the answer that "Excellency"

> would be very much pleased to see me. So I went up to his room and to my sorrow found Bunsen very much aged and reduced in flesh. He was very cordial, made me sit on the sofa next to him, told me that he had an indistinct recollection of me and then, like any other common mortal, began to complain of his ills ... Besides the servant girl, who was downstairs, the old man hasn't a soul in the building to take care of him. He asked me a thousand and one questions about myself, doings and family. I told him about the torsion scale and said I would bring him one to look at the next day. He said he would be pleased to see it provided he was not too weak. After spending an hour and a half with him, I came back to the hotel. Eda and Lilly [Springer's wife and cousin] then went with me to a florist and had the finest basket of flowers made up that we could obtain in Heidelberg and I sent them to him with my card.
>
> This morning I took my scale with me and called again. When I went upstairs he almost shook my hand off thanking me for my attention. I then showed him my scale. I never yet have seen anybody so delighted with it as he was. He did not know what to admire most – the ingenuity of the construction, the principle, or the wonderful machinery work on the same, including the handsome appearance. But what seemed to delight him the most was that one of his old students should be the co-inventor of the instrument. He asked me whether I would lend it to him for a day or so so that he could examine it at his leisure. I then told him I had brought it along from America with the intention of offering it to him as a slight token of respect. He at first thought it was too much to accept, but afterwards he took it and said he would have it set up in his private room under a glass case.
>
> I spent the whole morning with him, then bid him goodbye, perhaps forever. If his disease lasts much longer, it will ruin all hopes for recovery [But, of course, Bunsen would live for yet another decade]. It is a great misfortune that such men ever grow old, for today he is still the wonderful scholar and the kind-hearted teacher that I loved and respected of yore.

Before leaving that day, Springer had a private conversation with the servant girl about Bunsen's care and possible needs. According to Springer's granddaughter, the girl told him that Bunsen could no longer afford the morning sweet rolls that he dearly loved to have with his breakfast. As a result, Springer set up a tab, to be billed to him in the United States on a yearly basis, with the local baker to anonymously supply Bunsen with his morning treat for the remaining years of his life. Alas, I have no information on what became of the "Springer sweet roll endowment" after Bunsen's death.

Canonization

The claims of poverty made by Bunsen's housekeeper are a bit difficult to believe given that he was virtually canonized after his retirement. Interestingly, this process was initiated, not by his former students, but rather by the German chemist, Wilhelm Ostwald, and started, as already mentioned, in the 1890s with the republication of his classic researches on organoarsenic compounds (*14*), photochemistry (*15*), and spectroscopy (*16*) as part of Ostwald's newly founded history of science series, *Klassiker der Exakten Wissenschaften.* It continued after Bunsen's death with the reorganization and renaming in 1902 of the Deutsche Elektrochemische Gesellschaft as the Deutschen Bunsen-Gesellschaft für Physikalische Chemie (*35*) and its sponsorship in 1904 of the publication of the definitive three-volume edition of Bunsen's collected papers (*16*). Concomitant with these events was the erection of an impressive statue (Figure 19) and elaborate memorial to Bunsen in Heidelberg and the placement of a memorial bas-relief on the headstone marking his grave (Figure 20). Consistent with Oesper's penchant for visiting and photographing the graves of famous chemists (his wife once suggested he should form a Society for Dead Chemists), the Oesper Collections contain numerous photographs of both the Bunsen statue and grave site.

Figure 19. The statue of Bunsen found at Heidelberg. This was part of an elaborate outdoor memorial. Courtesy of the Oesper Collections.

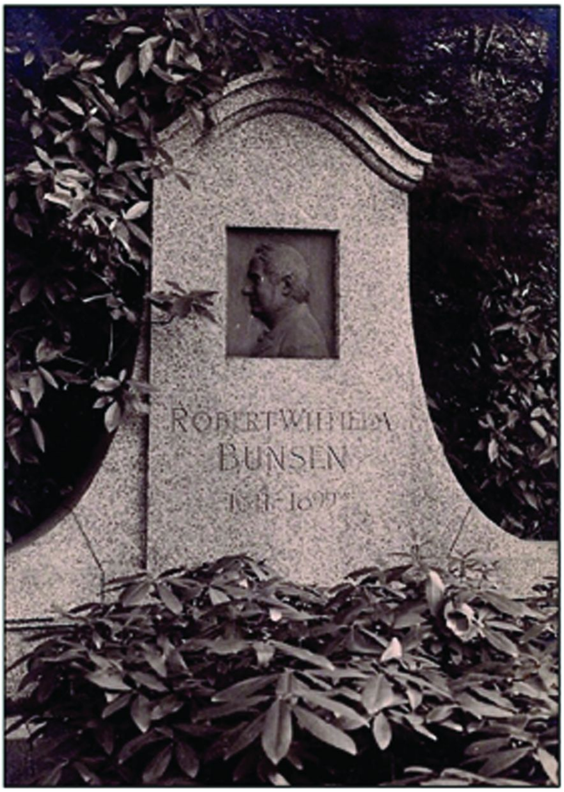


Figure 20. Bunsen's grave site showing his portrait in bas-relief. Courtesy of the Oesper Collections.

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Chapter 3

Who Was the Real Joseph Black?

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Today the reputation of Scottish chemist, Joseph Black (1728−1799), lies largely on his characterisation of 'fixed air' (carbon dioxide) and for his conceptualisation and measurement of latent heat. Yet the research involved to develop these ideas took him only fourteen years out of a career three times that length. It was complete by 1766, the year in which he took up the chemistry chair at Edinburgh University. This chapter looks beyond Black's fundamental research activities and considers the contribution which he made to the developing industrialisation of Scotland, as well as considering his role as perhaps the most renowned chemistry teacher of his time. Black's recently published correspondence helps fill-out many previously unknown aspects of his character and shows him to be a significant member of the Scottish Enlightenment community.

Most work conducted by historians on scientific figures tends to concentrate, not surprisingly, on their particular scientific contributions. This results in a rather narrow way of looking at the individual concerned and does not provide clues, or an explanation, about the cultural context in which the scientist has worked and what influencing forces there may have been. Joseph Black (Figure 1) has largely been treated in this way. All that he is remembered for, if he is remembered at all, is that he was the Scottish chemist who 'discovered' fixed air, or carbon dioxide, and that he developed the concept of latent heat. These two,

In Characters in Chemistry: A Celebration of the Humanity of Chemistry; Patterson, G., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

admittedly significant, developments were conducted over a period of fourteen years within a professional lifetime of 47 years. This short period is what nearly every historian has concentrated on. There is only one biography which takes a broader view, and this is William Ramsay's *Life and Letters of Joseph Black*, published as long ago as 1918. Even so, Ramsay had little interest in the cultural context in which Black developed intellectually and later operated. This narrow vision is not unusual, but there have been a few biographies of other scientists which consider a broader perspective, for example Frank Manuel's *Portrait of Isaac Newton* of 1968, which has been described as a psychoanalytic study, and Geoffrey Cantor's *Michael Faraday: Sandemanian and Scientist*, published in 1993, which considers Faraday's scientific output in relation to his religious belief. Black worked during a period which has become known as the Scottish Enlightenment alongside major intellectual figures such as David Hume, Adam Ferguson, William Cullen and James Hutton, whom he could count as his friends. The environment in which he operated was culturally multi-faceted. As a nation, Scotland was changing fast in a variety of ways, and in some of these Black was playing a significant role. He needs to be considered as a many-sided personality, not just as one who made a couple of important scientific discoveries at an early stage in his career.

One of the problems in dealing with Black is to know where to turn to for evidence. For most scientists, the first port of call is their publications. Though many of his friends urged him on, Black published very little and his contemporary fame arose largely from his reputation as being a remarkable teacher who attracted students from far and wide. Black's lectures it is true, were published but it was not Black who edited them (*1*). This was done after his death by his former colleague, John Robison, professor of natural philosophy at Edinburgh. Robison regretted that he had taken on the task when he examined the notes from which Black lectured. Writing in a letter of 23 July 1800 to James Watt, he said, "By far the greater part are loose scraps of paper, patched and pasted over sending the reader backward and forward thro' several pages… There is not two pages that can appear in print in its present form. I am really in great distress (*2*)." Because of this, Robison's text needs to be treated with care. There is a large body of 'students'notes', but on examination, nearly all of them were written down not by the students themselves but by professional scribes, who did not attend the lecture courses but would have copied them from some earlier notes, which themselves were probably copies. Though several of these notes bear a date and the owners' name, this evidence can therefore be misleading. Letters are invariably valuable, being less formal than publications and are often revealing in more personal details. In Black's case, they are a major source of information. Of his once, probably voluminous, correspondence, 355 letters written by Black have been traced, and 408 letters to him survive. These have all been recently published (*3*). Two things must be pointed out. First, it is clear that only a small proportion of the total number of letters once written now still exist. Secondly, most of the letters are of a 'professional' nature, written to and from colleagues, and those involved in the world of chemistry. Social letters are very few and far between, which raises the question as to whether this category of letter was disposed of by Black, or subsequent owners, or did Black simply never write this kind of letter?

The former explanation is the more probable, because a proportion of the surviving letters are to his family members and these deal with domestic and non-chemistry topics. Black was certainly capable of leaving his intense world of chemistry.

Figure 1. Joseph Black teaching at Edinburgh University. Etching by John Kay, 1787.

Although it is not the intention of this paper to deal in detail with Black's major contributions to his subject, it would be perverse not to give an outline of this work to provide an explanation of his reputation. A few background biographical details may also be useful. He was born in Bordeaux, France, into a mercantile family. His father and his earlier ancestors were of Irish stock, probably deriving from one of those families which had emigrated to Ireland from the west of Scotland early in the seventeenth century. John Black was a man of some substance who counted among his friends the philosopher Montesquieu. Black's mother, Margaret Gordon. came from Aberdeenshire. She bore fifteen children, of whom two died in infancy, Joseph being the ninth child. The well-to-do family was one of a number from Ireland involved in the wine trade and in ships' victualing. Black was first educated at home by his mother but at the age of twelve he was sent to school in Belfast and four years later he went to Glasgow University to study for a general arts degree. Towards the end of his course his father told him that his further studies should lead to a career. Black chose medicine. The reason is not entirely clear – there had been no doctors amongst his ancestors – but it may have had something to do with the fact that an inspiring young teacher, William Cullen, had been appointed to a new post at the University, a lectureship in chemistry. Cullen nurtured Black's early fascination with his subject and persuaded him to conduct experiments in his laboratory. This was unusual at the time. Up till then, chemistry in Scotland had been taught entirely for its use in pharmaceutical practice. Teachers displayed drug preparation to their pupils but did not have them participate in practical work. Cullen had suffered the boredom of this approach when he was a student at Edinburgh University, where chemistry was taught by the dull Andrew Plummer. He was determined to develop chemistry in a new light, showing how it could be seen as relevant to manufactures and industry. Moreover, he wanted to develop chemistry's analytical basis, just as Newton had transformed the study of natural philosophy in the previous century. Few students responded positively to Cullen's mission to get them involved in experimental work. Black was the exception.

Black almost certainly started to question the nature of alkaline substances while still at Glasgow, and this would form the topic of his earliest researches. In 1752 he decided to move to the east of Scotland to finish off his medical degree at Edinburgh, doubtless with Cullen's approval. (The shifting of students from one university to another was not unusual at the time.) Edinburgh had developed a more prestigious medical school than Glasgow and it had a larger faculty. To complete his MD degree Black would have to write a thesis in Latin and have it published, and he chose as his research topic the chemical properties of an alkali, magnesia alba (later called basic magnesium carbonate). This was not the obvious choice. The reason that he avoided investigating 'fixed alkali' (calcium carbonate) was that there was a dispute between two of the Edinburgh medical professors, Robert Whytt and Charles Alston, as to whether limestone or oyster shells made a more effective kind of limewater for dissolving urinary stones. As Black wrote to his father, "I found it proper to lay aside lime water which I had chosen for the subject of my Thesis. It was difficult and would have appeared presumptuous in me to have attempted some points about which two of the Professors themselves are disputing (*4*)." This response demonstrates Black's instinctively non-adversarial character, preferring not to involve himself in quarrels: a couplet in a poem written towards the end of his life said of him, "Disputes he shunn'd, nor car'd for noisy fame;/ And peace forever was his darling aim (*5*)." Black's work was innovatory in that he conducted a cycle of experiments in which he weighed the reacting substances at every stage. By doing this, he was able to show that 'fixed air' (carbon dioxide) was a component of the alkali he was testing. Black was acutely aware that the faculty might not consider such a chemically-focused piece of research appropriate for a medical degree, so he added a section to his dissertation in which he discussed the use of magnesia alba as an aid to digestion; this appears in the title of the work as (in translation) 'On the Acid Humors arising from Food'. Black submitted his thesis in 1754. It was warmly received and he duly qualified as a doctor (*6*). His father was inordinately proud of his son's achievement and sent a copy to Montesquieu. The correspondence between John Black and Montesquieu was something Black was keen to preserve, and the copies of the letters he had made still survive (*7*).

Black had decided that he did not want make his career as a physician: he aspired to work as an academic chemist. Nevertheless, at the age of 26, Black had to earn a living. He toyed with the idea of going to London, but he simply did not like the idea of moving around the country. He spent two years after graduation in continuing his research into alkalis and, to make some money, established some kind of shop and did a bit of doctoring. No longer having to worry about the Whytt/Alston dispute, he moved on to investigate the properties of calcium carbonate. It was this research which can be seen as a key moment in the development of pneumatic chemistry, for he showed that his 'fixed air' was a gas with distinctive chemical properties from atmospheric air. This work did appear in print, in 1756, and it was to be his most substantial publication (*8*). During the course of the work, Andrew Plummer died, and Black, supported by the faculty, briefly entertained hopes that he might be appointed professor of chemistry in Edinburgh. This was not a decision to be taken by the University but, rather strangely, by the Town Council of Edinburgh who were the University's patron. Beyond the Council there were other, powerful aristocratic influences at work and it were these that decided that when he could be made available, Cullen should be brought over from Glasgow as Plummer's successor. Black did teach briefly in Edinburgh in a temporary role but he was able to secure Cullen's job in Glasgow and both men were anxious that this unsettling episode would not affect their friendship.

Black established himself back in the west of Scotland rapidly and for the next decade was to immerse himself into teaching and research, whilst involving himself in the institutional and social life of Glasgow. He was twice elected President of the College of Physicians and Surgeons (1759−1761 and 1765−1766) and he acted in the time-consuming role as Dean to the Senate of Glasgow University (1762−1766). Unsurprisingly, historians have concentrated much more on Black's new direction of research in which he developed the concept of latent heat. He had been aware of anomalies concerning water, including Fahrenheit's observation that heat is emitted from supercooled water when it freezes to form ice and that when water is heated it does not suddenly all turn to steam when it attains its boiling point. Conducting experiments on freezing and boiling water, he was able to measure the new property, which he himself termed 'latent heat', in terms of degrees Fahrenheit. This story cannot be complete without considering Black's friendship with another new employee of the University, an artisan employed as mathematical instrument maker, James Watt. One of Watt's tasks was to repair a model Newcomen engine used in teaching natural philosophy, and, famously, it was his work on this which led him to thoughts about how the efficiency of steam engines could be improved. The outcome was the double cylinder, which allowed for the condensation of steam at a distance from the main cylinder and piston driving the engine. Black and Watt were working in very similar areas, though with different aims, one theoretical and the other practical. The question which has been asked is whether each man knew of the other's experiments. They denied this later in life, though it is difficult to believe they were unaware of what the other was doing. They were obviously closely involved with each other: Black helped Watt with his costs, and he became a partner in Watt's retail ventures (*9*). Black never published his work on latent heat. He started teaching his new doctrine to his students early in his Glasgow career, maybe as soon as the 1757−1758 session. It seems that he also announced his concept at a meeting of the Literary Society of Glasgow in April 1762, a club which attracted most of the Glasgow intelligentsia. For much of the rest of his life, Black's friends would urge him to put his ideas into print, realising that his work would be ruthlessly plagiarised, which it was. As Watt wrote to him as late as 1784, "I cannot bear to see so many people adorning themselves with your feathers" (*10*). Whether the cause was innate modesty, laziness or writer's block is difficult to say. It may be that Black felt that he had done enough to establish his primacy in the idea by simply teaching the concept to hundreds of pupils, year after year. Certainly his reputation as the author of latent heat has survived over the centuries without a word in print having been written on the subject by Black himself.

In 1766, following a complicated series of manoeuvrings of academic posts, Black was called to Edinburgh to take up the chair of chemistry, Cullen having been moved sideways to a purely medical professorship. From the moment he returned, Black stopped conducting pure research into what became known as philosophical chemistry, and it is at this point that most interest in him by historians ceases. Yet he was to spend the next thirty years deeply immersed in the teaching of his subject and in acting, essentially, as consultant to those wishing to develop the chemical industry in Scotland. If challenged as to what his priority as a chemist was in life, Black would probably have replied that it was his teaching. There can be no question that it was in this area that he excelled. Every year he taught a series of 120−130 chemical lectures, starting in November and finishing in May. These were held on five mornings of every week, and if he felt he was falling behind, he taught on Saturdays as well. There are many records of his brilliance as a teacher: for example, the future Lord Chancellor, Henry Brougham, who was present at one of Black's last courses, wrote,

> "it was perfect philosophical calmness; there was no effort; it was an easy and graceful conversation. The voice was low but perfectly distinct and audible through the whole of a large hall crowded in every part with mutely attentive listeners. In one department of his lecture he exceeded any I have known, the neatness and unvarying success with which all the manipulations of his experiments were performed. His correct eye and steady hand contributed to the one; his admirable, foreseeing and providing for every emergency, secured the other. I have seen him pour boiling water or boiling acid from a vessel that had no spout into a tube, holding it at such a distance as made the stream's diameter small, and so vertical that not a drop was spilt (*11*)."

Black's classes were very large – in some years, they exceeded 300 subscribers. Only a small proportion of these were students who would later graduate in medicine. A larger proportion was composed of surgeon apprentices, but by far the largest group were those who simply wanted to learn something about chemistry (*12*). Some of the apparatus with which Black taught survives and much of it is large in size, presumably so that those at the back of his class could see what going on (*13*).

Black's course changed gradually through his career, though he was not anxious to take on new ideas until they had been thoroughly tested. He was only slowly convinced by Lavoisier's proposals about the role of oxygen in combustion and respiration, though his students pressed him to accept it. Ultimately, though, he gave up believing in the Phlogiston Theory and he wrote to Lavoisier to congratulate him on his new System ("I am satisfyed that it is infinitely better supported than the former Doctrine") (*14*). Black continued teaching until he was quite an old man, in eighteenth century terms. His last lectures were given when he was 67 years old. By then he had selected his successor and Thomas Charles Hope took over his teaching in a seamless manner from 1795.

Many of Black's pupils who became physicians remained in contact with him after graduating by means of letter-writing. They usually asked Black his opinion on chemical medical matters and he responded to them, no matter how naïve were their questions. A number of them sent Black information, whilst others sent samples of minerals (Black built up a significant collection). Occasionally, some members of his audience were already established chemists. One of these was Lorenz von Crell from Hemstedt in Germany, who attended Black's classes from 1769−1771. Crell was to publish the first chemical periodical, the *Chemisches Journal*, which first appeared in 1778. He wrote a number of detailed letters to Black about developments on the Continent and he expected Black to respond with news of his own. When Black discovered that Crell had published one of his letters without permission he became irritated and the correspondence ceased (*15*). This reaction may be another facet of Black's aversion to publish. In this case, he had unwittingly submitted a publishable text without realizing how it would be used.

Black's contribution to the developing industrialization of Scotland was considerable during this second Edinburgh phase of his life. At the beginning of the eighteenth century, Scotland was a small independent nation with just over one million inhabitants. Never wealthy, economically it had recently declined further in comparison with its southern neighbour, England. There was a specific reason for this: at the end of the previous century, an ambitious and foolhardy scheme was entered into to establish a trading colony in what is now Panama. This investment used up much of available Scottish finance, and the Darien Scheme, as it was called, collapsed. Scotland was in an even more difficult economic position, and the solution which many of the Scottish aristocracy came to was that by giving up its independent parliament and uniting with England, it should become part of a 'Great Britain'. The advantage to Scotland would be that trade barriers would cease to exist and industrial expansion would follow, taking advantage of the much larger market to the South. This change occurred in 1707 and in the longer term Scotland prospered but the benefits took some decades to come through. In 1727 the British parliament voted an annual sum of £6000 to a Board of Fisheries and Manufactures to identify methods to increase the output and improve the quality of products, some of the advice being sought from the academic community, though it took time to establish the infrastructure of the new body.

Gradually through the century new attitudes were to develop, with landowners and investors starting to see the possibilities for change. In 1749, a major sulfuric acid works was established outside Edinburgh at Portobello, and a year later, a large ironworks got under way at Carron in central Scotland. Agricultural practices started to improve and become more efficient. But what was needed was chemical expertise, and Joseph Black was just the person to supply this. His surviving correspondence bears this out, a large proportion of the letters seeking Black's advice on a very diverse range of problems. These include such matters as metal extraction, glass-making, sugar refining, bleaching, furnace design, fertilisers, vinegar production, and so on. He corresponded freely with the aristocracy who were doing their best to improve their land, their industrial enterprises and their bank balances. A judge, Lord Kames, wanted to know how he could drain his land and he and Black started to get fascinated about the water-retaining properties of clay. The Earl of Hopetoun wanted help with lead, copper and silver extraction from ores found on his bleak estate in the west of Scotland. Lord Dundonald wanted to set up a tar manufactory by distilling coal at Culross on the north shore of the Firth of Forth. All wrote to Black, and all got carefully considered replies, including analyses of samples which had been sent to him.

It was not just the chemistry of these processes which Black advised on. It was necessary to know whether the proposals were financially viable. Here again, Black was helpful. Concerning Lord Dundonald's tar manufactory, Black did some very detailed calculations which considered the costs and the returns, including income which could be expected from by-products (*16*). He realised that the value of the tar could vary according to demand. A major use for it was to coat the bottom of ships to prevent the wood from being eaten by worms. Black argued that the value depended on whether Britain was at war or not – if there was war, the Navy would pay twice as much than if the country were at peace. Such subtleties brought him praise from the prominent Scottish lawyer, Sir John Dalrymple, who called Black, "the best judge, perhaps in Europe, of such inventions (*17*)."

In addition to these private arrangements, Black advised the Board of Manufactures, especially on the subject of bleaching. Linen was just as important to the Scottish economy as it was to the Irish. But bleaching linen was inefficient. Having woven the fabric it was soaked in sour milk and laid out on land, called bleachfields, for the sun to change its colour from grey to white. However, Scotland is not known for its ready supply of the sun. Alternative, more rapid, methods were sought, and alkalis were suggested. Supplies were not easily available and Black advised on sources obtained by burning ferns and leaching out the 'pearl ashes' (potassium carbonate) (*18*). Dilute sulfuric acid was also used, though there were worries about it damaging the cloth fibers, and it was not until the end of the eighteenth century that the much more efficient and widely used method of using hypochlorite became available. Black was also asked for his advice by the tax revenue authorities. They wanted to know how coal could be distinguished from culm, which is a low-quality coal and not subject to taxation (*19*). A second enquiry concerned the nature of bittern, which was the mixture of salts remaining when sea water has been boiled and common salt extracted. Black was happy to conduct the analysis, but he made it clear that he wanted nothing to do with the formulation of legislation (*20*).

It might be thought that consultancy would have made Black a wealthy man. But there is nothing in the letters from landowners which indicates that Black was ever offered a fee (the only gift mentioned was when Lord Hopetoun gave Black an antique gem). However, Black died a fairly rich man, his estate being worth about £20,000 when he died in 1799 (about $3.5m in today's terms). If income did not arise from consultancy, there would appear to be only two other major sources. Though Black may have been a reluctant physician, he was involved in some medical practice throughout his life and he acted for his friends (the philosopher David Hume amongst them, whom he treated during his final illness) (*21*). He and William Cullen were sometimes asked their opinion on how to treat difficult medical cases and it is certain that some of these were wealthy patients. A number of opinions survive, but fees are never mentioned in any of them. Black's work as part-time physician lasted well into his old age; in 1790 he referred in one of his letters to the "moderate share of practice which I have in town". The other major source of income was from his students. Black received no salary from Edinburgh University, but he charged each student three guineas for attending a course of lectures and he could retain the income. In some years more than 300 students registered for the chemistry course, which would have resulted in a gross income of nearly one thousand pounds, though his expenses have to be taken into account. He employed a laboratory assistant to help prepare the experiments and he was responsible for the cost of the apparatus and chemicals. As well as his official courses of lectures geared to medical students, there is evidence that he conducted private courses (one of his ordinary students, Sylas Neville, complained that Black seemed exhausted when he arrived to give his normal course later in the morning). One of his special series was for lawyers, a professional class which proliferated in Edinburgh. James Boswell, associate of Dr Samuel Johnson, attended these in 1775 and briefly commented on them. On one occasion he said that his curiosity was not roused by what he experienced, but when on another occasion the subject was gold, his attention was held (*22*). Another, minor source of income was from an emolument which he earned from being the King's Physician in Scotland (as King George III never visited Scotland, this can be considered a sinecure). Something about Black's investments are known from his papers. He was a shareholder in the Culcreach Cotton Company and the Edinburgh and Leith Glassworks. Part of his income was invested in government bonds and annuities. His brothers seem continually to have been at the edge of bankruptcy and Black bailed them out, though he always charged interest on his loans and gave them fraternal advice about how to care for their finances in the future. He also bankrolled some industrial enterprises. He helped James Watt at a particularly critical time when his engine business was not covering its costs, and he loaned money to John Roebuck who had established the Carron Ironworks. Black was careful with his money, but knew what it was like to lose it. He had kept an account with the Ayr Bank, which failed in June 1772, responding with equanimity. His colleague John Robison wrote, "he lost three-fourths of all the fruits of his labours, by the failure of the house where he lodged his money. He forsaw this failure for two years; yet no man ever observed the smallest appearance of fretfulness (*23*).”

Black didn’t spend all his time conducting experiments, giving advice and teaching. He was gregarious, in a controlled sort of way, and could be called called ‘clubbable’. Club life in Edinburgh taverns played a central role in Enlightenment Scotland. Men from very different disciplines chatted and gossiped together, whilst getting gently enebriated through the afternoon. There were plenty of clubs to choose from. Some were serious and professional, some were political, while others were purely sociable (and some were even established for members to indulge in obscene practices). In Edinburgh there were clubs for doctors, the main ones being called the Aesculapian and the Harveian (both survive to the present day). The latter was named after the physician William Harvey and its declared purpose was “to celebrate the circulation of the blood by the circulation of the glass” (*24*). Significantly, Black did not join a medical club – he preferred more mixed intellectual company. Black was a member of at least two of the more social clubs, the Poker and the Oyster. Black was a co-founder of the latter, along with the economist Adam Smith and the geologist, James Hutton. According to another member, the mathematician John Playfair, “the chief delight of the Oyster Club was to listen to the conversation of the three founders (*25*).”

Black was reputed to enjoy parties. His friend John Robison wrote of this: “He was a stranger to none of the elegant accomplishments of life. He therefore easily fell into any topic of conversation… he sung, and performed on the flute, with great taste and feeling.” Black also enjoyed social life by entertaining at home. He gave weekly supper parties in his fashionable new Nicholson Street house, which cost him £1470 and which he occupied from 1781. We know the menu for at least one of these from his household accounts: it was chicken, cowhead and sausages, with apple dumplings afterwards (though he did not indulge in the rich food himself). It is frustrating that we have little idea about what the inside of his house was like. There is no record of pictures or of furniture. A list of his silverware exists, which was modest for a man in his position. He was a collector of minerals and it is probable that Black kept his best specimens in his house, as other collectors did (when Watt’s industrial partner Matthew Boulton had a house built for him in Birmingham, it included a special room for his collection, which he called his *fossilry*). Black was for ever asking friends to send him specimens of rocks and minerals when on their travels. One of several who responded was the German surveyor Rudolf Raspe (the author of the *Baron Műnchhausen* stories) who in 1792 sent Black a “good Specimen of clean Aerated Barytes” (barium carbonate) (*26*). Undoubtedly Black’s house would have incorporated a library. Not a great deal is known about which books he owned, there being no book sale after his death. Some evidence can be gauged by knowing which volumes he borrowed from Edinburgh University Library (records survive) as he would not have removed books which he already owned. There are a few pieces of evidence in letters. Lavoisier sent him a bundle of books in 1790 and though these are not specified, it would be odd if this did not include the *Traité Elémentaire de Chimie*, published in the previous year. It might be assumed that there would also have been Robert Kerr’s translation of this work which was published in Edinburgh in 1790. Lorenz von Crell sent copies his *Chemisches Journal* in 1779. The 1774, 1783 and

1792 editions of the Edinburgh Pharmocopoeia, published by the Royal College of Physicians of Edinburgh, must surely have been owned by Black because he helped to edit them, and a work on thermometers dedicated to Black was likely to have found a place on his shelves (*27*). It is clear that Black read widely, including works of the classics, and he seems to have had a particular penchant for books on travel and exploration (perhaps to compensate for the fact that he was averse to leaving home). It was with genuine delight that he received from his nephew George Black a book of verse of the mystical fourteenth century Persian writer, Hafiz. He was subscriber to a number of works, including a 1787 edition of Robert Burns' poetry. Black looked after another nephew, Jamey Black, in his house in 1783 while he was dying of tuberculosis, and touchingly, Black borrowed a copy of *Arabian Night Entertainments* from the University to keep him amused.

Black disliked travelling (he wrote to his bother George in 1792, "for a person like me, home is the most comfortable") (*28*). But many of his correspondents nagged him to come to visit them, especially James Watt, and finally he was persuaded. This was the only major journey he made after he came to Edinburgh, from July to September 1788. First he went to Ireland by boat, to Belfast and Dublin, to visit his brothers and sisters. Then he re-crossed the Irish Channel to inspect the Cast Plate Glass Company at Ravenshead in Lancashire where his brother Alexander had responsibilities. From there he went to see the famous potter Josiah Wedgwood at Etruria in Staffordshire, and thence he travelled to Birmingham, where Watt had been working since 1774 in partnership with Matthew Boulton, constructing and installing steam engines all over Britain. It is just possible that in Birmingham he came across Joseph Priestley, who was a preacher there, and he may have attended a meeting of the famous Lunar Society, the informal dining club which included many of the intellectual elite of the English Midlands. Thence he went to Oxford, staying with the Dean of Christ Church (and meeting the mineralogist William Thomson), to Slough to see the astronomer William Herschel and finally on to London for a month's stay.

It is known what he intended to do in London because there survives a scrap of paper which lists in Black's handwriting the places and people he wished to visit (*29*). This is very revealing about his contacts, interests and tastes. There are 50 names on the list. Included are a number of churches which were designed by Christopher Wren following the 1666 Great Fire of London, and Westminster Abbey. Apothecary's Hall, home of the Society of Apothecaries, is listed and there he purchased ambergris. He called in at the scientific instrument making firm of Nairne and Blunt, where he bought an engraving of William Herschel, whom he had recently visited. He visited Josiah Wedgwood's retail outlet in Greek Street. At Peter Elmsley's bookshop in the Strand he picked up two books he had ordered; their titles are not specified but it is known that Elmsley specialised in French publications. He visited the famous Scottish anatomist and teacher, John Hunter, in Leicester Square where his anatomy theatre and museum were located. He sought out Robert Adam, the architect, who had been commissioned to rebuild Edinburgh University. The engraver James Tassie created a portrait of him. He probably bought minerals for his collection from the dealer Jacob Foster, and a violin from William Morrison which he may have been learning to play (in 1792 he would ask his brother Alexander to send him a copy of Francesco Geminiani's

The Art of Playing on the Violin). He bought a tea pot from Chippendales costing £7. 1s. He called in on the revolutionary patriot from Corsica, Pasquale Paoli, who had become something of a London celebrity. Black does not mention the Royal Society or the British Museum, both of which he must have wanted to visit, but from another source, it is known that he dined with the President of the Royal Society, Sir Joseph Banks, on 7 August. The British Museum, which had been open to visitors from January 1759 in Montagu House, Bloomsbury, may well have been closed for the summer.

This London visit reveals Black's broad intellectual interests and his network of contacts. Discovering more about his more personal life, for example his religious attitudes and private relationships, is much more difficult. Unlike other letter writers of the time, religious opinion is nearly entirely absent from his texts. Only on seven occasions does the word 'God' appear, and that is always in relation to the illness of friends, or their recovery. John Black, his Presbyterian father, was clearly a man of strong feelings and frequently invoked the Almighty when writing to his family. When he bought an estate, Ballintaggert in County Down, he discovered that its Irish meaning was 'Priests' Place' and he promptly renamed it North Blamount. Black's parents' fervour was not passed on to their son. When Black was teaching in Glasgow, he had argued in the University Senate against the provision of a college chapel, and again in Edinburgh 24 years later he attempted to get the University to withdraw plans to build a chapel in the Robert Adam-design for the college building which was being planned (*29*). Perhaps most revealing is what he writes following David Hume's celebrated death in August 1776. Hume was a celebrated atheist, but when he was dying, many expected there to be a last-minute conversion to religion. It never came, and Black, writing to Adam Smith about Hume's final moments said, "he died in such a happy composure of mind that nothing could exceed it (*30*)."

Concerning friends, it is known of his close relationships with academic colleagues even though there is little correspondence with those with whom he was in daily contact. He clearly knew many of those who made demands on his chemical skills: the aristocrats, landowners and wealthy merchants. He was subservient to a degree, but did not always respond to their very beck and call when they wanted him to visit their estates. He seems to have little regard for class barriers in general. He befriended James Watt at an early stage in his career and he had great warmth for a local manufacturer, Archibald Geddes, manager of the Edinburgh and Leith Glasshouse. There is little evidence about the detailed nature of this relationship except that Black, being interested in all scientific and technical matters, assisted with the design of the glass kilns. Practically nothing is known about his relationships with women. Very little is said on the subject by his memorialists – John Robison simply wrote, "the young ladies were proud of Dr. Black's approbation of their taste in matters of ornament." Of the 763 letters to and from Black, only 10 are from women and 6 are to them. Though no one has accused Black of being a misogynist, this is a very small proportion, even allowing for the custom of the time. He enjoyed the company of some of his nieces, and of Anne Watt in particular. He was impressed by the Russian bluestocking Princess Dashkova, who established a salon in Edinburgh while her sons were studying, and the only substantial letter written to a woman is a detailed account to her of Hutton's theory of the earth (*31*).

Black often complained about his health in his letters (especially to Watt, who complained back). He may have had a long-term chronic illness, and he put himself on a strict regimen, eating no meat and drinking milk. He took exercise by riding. When he felt he was getting too old for this, he bought himself an exercise machine (*32*). Black put his affairs in order well before his death. He decided that all his property should be sold and that his estate should be divided into 10,000 shares, which in his will he apportioned with detailed care amongst his surviving relatives. He declined physically from the mid-1790s and he died suddenly, but in style, on 6 December 1799 when his servant found him dead in his chair with a bowl of milk balanced between his thighs. He received a grand University funeral (*33*).

In spite of the newly published correspondence providing a good source of evidence of his own later work and attitudes to the science of his day, Black as a person still remains something of an enigma. This is because the letters deal so overwhelmingly with scientific and technical matters. Other kinds of letters, apart from those to and from family members, are largely not to be found. To obtain a more rounded picture it is necessary to seek evidence elsewhere, such as comments from friends and obituaries. Black was a private man who kept careful control of his life and it likely that he deliberately filtered out parts of the correspondence. He had decided the historical image of himself which he wanted to leave for posterity.

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Chapter 4

The Quaker Rustic as Natural Philosopher: John Dalton and His Social Context

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For a leading man of science ca. 1800, John Dalton (1766−1842) had risen from surprisingly modest circumstances. This chapter explores the life history and personality of the founder of atomic theory in chemistry, with useful comparisons and contrasts to his somewhat younger contemporary, Humphry Davy (1778−1829).

On 23 May 1802 the renowned English caricaturist James Gillray published what would become one of his more famous cartoons, a humorous depiction of a lecture on the chemistry of gases at the (then newly-established) Royal Institution in Albemarle Street, Mayfair, London. We see a youthful Humphry Davy holding a bellows, assisting the white-haired professor of chemistry, Thomas Garnett, and we see the American founder of the Royal Institution, Count Rumford, guarding the door in the right background. Just eight days after the publication of this print, Garnett resigned his post due to declining health, and his protégé Davy, then just 23 years old, succeeded to the position of professor of chemistry. Davy quickly established a reputation as a spellbinding lecturer, as well as the author of pathbreaking new chemical research on gases, on electrochemistry, and on chemistry applied to the trades. Handsome, eloquent, and scientifically brilliant, Davy became something of a matinee idol in the lecture theater, especially to the

In Characters in Chemistry: A Celebration of the Humanity of Chemistry; Patterson, G., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

aristocratic fair sex; one young lady reportedly sighed (*1*): "Those eyes were made for something besides poring over crucibles."

The year after the Gillray caricature appeared, the managers of the Royal Institution accepted the proposal of the Mancunian natural philosopher John Dalton (Figure 1) to present a course of twenty lectures on natural philosophy, this negotiation occurring at the very time that Dalton was privately developing his earliest ideas on the chemical atomic theory. Davy welcomed the thirty-seven-year-old Dalton to Albemarle Street when he arrived there on or about 17 December 1803, which by coincidence happened to be Davy's twenty-fifth birthday (*2*); it was just the second time that Dalton had ever seen London. Dalton stayed there over a month, in rooms adjoining Davy's. Here, quoting his letter from London to a friend in Manchester, are Dalton's own words (*3*):

> [Davy] is a very agreeable and intelligent young man, and we have interesting conversations in an evening; the principal failing in his character as a philosopher is that he does not smoke. Mr. Davy advised me to labour my first lecture; he told me the people here would be inclined to form their opinion from it … I studied and wrote for near two days, then calculated to a minute how long it would take me reading … The evening before [my first] lecture, Davy and I went into the [lecture] theatre; he made me read the whole of it, and went into the furthest corner; then he read it and I was the audience; we criticized upon each other's method. Next day [22 December 1803] I read it to an audience of about 150 or 200 people … They gave a very general plaudit at the conclusion. In general my [illustrative] experiments have uniformly succeeded, and I have never once faltered in the elucidation of them. In fact I can now enter the lecture room with as little emotion nearly as I can smoke a pipe with you on Sunday …

Clearly Dalton and Davy got along well on this, their first meeting. But these two men were very different, and the differences soon became evident. Along with his other virtues, Davy was a brilliant performer, and was not only scientifically but also socially ambitious—in truth, *very* ambitious. Before his 26th birthday he was made Fellow of the Royal Society. At the age of 33 he was knighted, henceforth always insisting on being addressed as Sir Humphry, and in the same year he married an extremely wealthy young socialite widow by the name of Jane Apreece. Thereafter he enjoyed the life of London aristocratic society. He was made a baronet, and president of the Royal Society, before his early death at the age of fifty.

It would be hard to imagine a greater contrast than with that of Davy's interlocutor in December of 1803. Dalton had been born in a small cottage in a tiny hamlet in northwestern England, the son of a poor woolen weaver and farmer. The nearest community was Cockermouth, with a population of a couple hundred souls, the next larger town being Kendal, 45 miles away. He was informally educated until the age of twelve, when he began teaching school himself. Thereafter he was essentially self-taught. “To all appearances,” an early biographer wrote (*4*), “he was like those around him, born to be a clodhopper.”

Figure 1. Dalton in 1814. Courtesy E.F. Smith Collection, University of Pennsylvania.

But appearances were deceiving. Dalton had a great advantage in life in having been born to a Quaker family that valued education, self-reliance, and a selfless striving for learning. From childhood until old age, Dalton applied himself indefatigably, hourly and daily, to his own education, and to that of those around him. He attained sufficient local reputation as a schoolmaster and author of original meteorological essays that when a dissenting academy in Manchester was looking for a new professor of natural philosophy an influential patron recommended Dalton, and the 27-year-old scholar moved from Kendal to that rising center of the early industrial revolution. He resigned this professorship a few years later, but he remained in Manchester for the rest of his life, earning his living as a private tutor in math and science.

Being a member of the Society of Friends also meant that Dalton was the polar opposite of Davy as regards ostentation and social ambition. It is certainly true that Dalton aspired to European reputation as a leading natural philosopher, and around the turn of the century he began to achieve that ambition by publishing a series of important papers on meteorology and the physics of gases. But in his personal life he believed deeply in Quaker "plainness": he dressed and lived simply and abstemiously, never married, abhorred the noise and pretention of London, and always retained his rural north-country Quaker manner of speech. He was neither an attractive lecturer like Davy, nor a master of experimental technique like Joseph-Louis Gay-Lussac or Jacob Berzelius. Some metropolitan sophisticates, presumably including Davy, found his unaffected provincial manners naïve, or even repellent. Most surely underestimated him. English society was nothing if not class-conscious, and Davy, who himself had obscure lower-middle-class origins (he was the son of a woodcarver in Penzance), was particularly susceptible to a kind of snobbish superiority toward those whom he considered his social inferiors.

But if Dalton remained something of a rustic, what he did have to his credit was great common sense, imagination, and a clever and intellectually courageous way of thinking about the unseen world of the unimaginably tiny. The regularities in combining proportions of the elements which we call stoichiometry were emerging just at this time, and to Dalton they provided insight into the atomic nature of matter. We know from his laboratory journal that on 6 September 1803 he carried out his first private calculations of relative atomic weights—the first such in history (*5*). Six weeks later he communicated these atomic weights orally in a paper presented to the Manchester Literary and Philosophical Society, but without telling his audience anything about how he had done the calculation (*6*). Two months after that, he delivered the course of lectures at the Royal Institution that I described above. In at least one of these lectures it appears that Dalton told this London audience about his new atomic theory (*7*, *8*), but apparently he provided no further details than he had given orally in Manchester, and he did not give the theory any special emphasis in this forum.

In a later reminiscence of this, his first experience at the Royal Institution (*9*), Dalton wrote of his "frequent conversations" with Davy on the merits of his atomic theory. He showed Davy how the latter's own recent analyses of the three then-known oxides of nitrogen could be interpreted as the direct consequence of three different atomic ratios of nitrogen to oxygen atoms in their respective molecules. Dalton said that he was "the more happy in this, as [Davy's] results formed some of the most excellent exemplifications of the [atomic] principles." But Davy's initial opinion of Dalton's theory was not particularly favorable; he thought that it was "more ingenious than important" or "more ingenious than correct." We can trust the accuracy of this report of Davy's opinion, for both Dalton (*10*) and Davy himself (*11*) later used virtually the same phrase in describing

Davy's first reaction to the theory. Four years later, in the preface of his *New System of Chemical Philosophy* which provided Dalton's first extended treatment of his theory, Dalton stated (*12*) that in January 1804 he had written out a brief description of the theory and left it, presumably with Davy, for publication in the journal of the Royal Institution. It never appeared there, a circumstance for which Davy was doubtless responsible.

To be fair, Davy's resistance to Dalton's theory was based on more than just social snobbery. Dalton, who had picked up in his program of self-study a kind of popular Newtonian natural philosophy, had adopted, apparently without reflection, the simple materialist ontology of matter that one could read into the famous passages at the end of Newon's *Opticks*. As a common-sense realist, Dalton believed in material imponderable fluids—especially the presumed matter of heat, caloric—and thought of his atoms as hard, spherical particles, like tiny unsplittable billiard balls. He was, in short, a scientist in the mold of an eighteenth-century materialist Enlightenment philosopher. By contrast, although he had been born just twelve years later, Davy breathed the charged air of the dawning Romantic era. He was a reductionist and an idealist, oriented toward a dynamical philosophy of nature, and opposed to naïve subtle fluids, microscopic mechanisms, and other intellectual symptoms of Enlightenment materialism. Dalton had proposed that each element was a distinct kind of matter, based on a unique variety of atom. To Davy this was repellent—nature could not be so complex, so multifarious, so ugly. Davy preferred to imagine that all the elements were composed, at a more fundamental level, of some sort of unitary entity that was more probably based on force and motion than on tiny chunks of insensible matter.

In the winter of 1809−1810 Dalton returned to the Royal Institution to give a second series of lectures on natural philosophy. In his presentation on January 27, Dalton cited Newton as his authority for his new theory of gases, stating (*13*) that Newton had demonstrated in the *Principia* that gases consist of "small particles or atoms of matter, which repel each other by a force increasing in proportion as their distance diminishes." But Dalton was mistaken—Newton had shown only that such a hypothetical model would entail the known gas laws. Three days later Dalton misquoted Newton once more (*14*), citing Query 31 from the *Opticks* to claim, incorrectly, that Newton believed in the kind of billiard-ball atoms that Dalton preferred, against the more dynamical-idealist notion urged by philosophers like Davy. Clearly, Dalton was proud to believe that he was following closely in Newton's footsteps, and by implication he was trading on Newton's fame to diminish rivals such as Davy. Dalton took equal pride in his (putative) striking physical resemblance to Newton (*15*). He even followed Newton in some of his self-referential comments; as Newton had done, Dalton proclaimed (*16*) that his scientific success had more to do with diligence than with genius: "If I have succeeded better than many who surround me," he wrote, "it has been chiefly, nay, I may say, almost solely from unwearied assiduity."

In this, at least, Dalton certainly spoke truly, as a few anecdotes concerning his private life will show. Shortly after his appointment as professor at the New College in Manchester, he wrote to a friend back home (*17*) that he was getting on very well, taking all meals with the other teachers and students (breakfast at 8:30, dinner at 1:30, tea at 5, supper at 8:30). He continued, "There is in this town a large library, furnished with the best books in every art, science, and language, which is open to all gratis; when thou art apprised of this and such-like circumstances, thou considerest me in my private apartments, undisturbed, having a good fire, and a philosophical apparatus around me, thou wilt be able to form an opinion whether I spend my time in slothful inactivity of body and mind." All was regularity, order … and work, work, work. All except on Thursday afternoons, when he would walk about three miles out into the country, to the Dog and Partridge Inn in Stretford, to play bowls (*18*).

Observers described Dalton (*19–21*) as "of strong rather than elegant proportions … rather above the middle size, five feet seven inches … robust, athletic, muscular, and stooped slightly as if hasting forward, for he was a rapid walker. His countenance was open and manly." "[His] manners were extremely simple … Amongst his intimate friends … he was exceedingly cheerful and [witty]." He was especially fond of a former Greek and Latin instructor at New College, William Johns. One day Mrs. Johns saw Dalton in the street, and asked (*22*) why he had not visited the family in some time. He answered, "Why, I don't know, but I have a mind to come live with you." Since the Johns family had a spare bedroom, this is exactly what happened. And since the Johns' home was across the street from the Manchester Literary and Philosophical Society where Dalton had a small study and laboratory, the arrangement suited everyone perfectly.

Dalton's work was clearly made easier by his bachelor lifestyle, but there is plenty of evidence that he was neither a misanthrope nor a misogynist. One must remember that Quakers held women to be full equals with men. He was certainly fully stricken by members of the fair sex at least three times, as he related in letters to his brother, and according to the reminiscences of a close friend (*23*). One of these was a young widow who was not only "engaging beyond all description," indeed "the handsomest woman in Manchester," but also, as he soon discovered, something of a scholar and a philosopher. "During my captivity," he continued, "which lasted about a week, I lost my appetite, and had other symptoms of bondage about me, as incoherent discourse, &c., but have now happily regained my freedom."

On the occasion of his second round of Royal Institution lectures in 1809−1810, Dalton wrote William Johns a long, newsy letter from London (*24*), in which he optimistically opined that "Davy is coming very fast into my views on chemical subjects." Then he described something of his life in London. "I should tell Mrs. Johns something of the fashions here, but it is so much out of my province, that I feel rather awkward. I see the belles of New Bond Street every day, but I am more taken up with their faces than their dresses. … Some of the ladies seem to have their dresses as tight round them as a drum, others throw them round like a blanket. I do not know how it happens, but I fancy pretty women look well either way."

There is actually some evidence that Davy was indeed coming around, in his own way, towards Dalton's views on atoms. Thomas Thomson later described (*25*) a conversation in the fall of 1807 in which he and Wollaston, both of whom advocated the atomic theory, were initially unable to convince

Davy of its truth, but that Davy was very soon thereafter fully converted by the arguments of his friend—and, twenty years later, his successor as president of the Royal Society—Davies Gilbert. In any case, Davy did present a version of atomic theory in his own textbook, *Elements of Chemical Philosophy*, published in 1812 (*26*). What Dalton had referred to as the relative weights of his "atoms," Davy applied the more neutral term "proportions." Dalton was no doubt pleased by this publication, which he surely interpreted as marking his victory in their longstanding argument. Soon after Davy's book appeared, Dalton wrote to Berzelius (*27*), once again metaphorically donning Newton's mantle: "The doctrine of definite proportions appears to me mysterious unless we adopt the atomic hypothesis. It appears like the mystical ratios of Kepler, which Newton so happily elucidated."

But Dalton was too optimistic about the opinions of others. To Davy, at least, Dalton was no Newton of chemistry. When the first Royal Medal was awarded to Dalton in 1826, Davy, as president of the Royal Society, had the honor of formally presenting it (Figure 2). His presentation text was superficially flattering, but the language was condescending at best, and parts of it could be considered insulting. Dalton's merits, Davy intoned (*28*), "resemble those of Kepler in astronomy. The causes of chemical change are as yet unknown, [as are] the laws by which they are governed." Regarding Dalton's putative atomistic predecessors, Davy pronounced the following verdict: "Mr. Dalton, as far as can be ascertained, was not acquainted with any of these publications, at least he never refers to them: and [no one] will hardly accuse him of willful plagiarism." And regarding the theory itself, he stated that Dalton "first laid down, clearly and numerically, the doctrine of multiples; and endeavored to express, by simple numbers, the weights of the bodies believed to be elementary. His first views, from their boldness and peculiarity, met with but little attention; but they were discussed and supported by Drs. Thomson and Wollaston; and the tables of chemical equivalents of this last gentleman, separates the practical part of the doctrine from the atomic or hypothetical part …" He then spoke feelingly of the merits of Gay-Lussac, Berzelius, William Wollaston, and William Prout, before returning to Dalton's atomic theory, and adding the following caution: "I hope you will understand that I am speaking of the fundamental principle, and not of the details as they are found in Mr. Dalton's system of chemical philosophy…"

To the modern reader, these words seem at best grudging and at worst hostile, but we must not be too hard on Davy. There were, in fact, major flaws and logical holes in Dalton's atomic theory, and the theory had not yet begun to prove its enormous value. No one knew how large or how heavy atoms were on any absolute scale, nor anything about their appearance or properties, nor whether atoms were actually indivisible or not, as would be implied by the etymology of the word "atom." No one knew how to determine the molecular formula of any compound whatever, not even such simple and centrally important substances as water, carbonic oxide, ammonia, or marsh gas. The elementary gases were confidently assumed to be monatomic, a mistake that was to introduce unneeded complexity and inconsistency into these calculations. Above all, without a way of determining formulas, even relative atomic weights were impossible to determine with any degree of confidence.

Figure 2. Dalton in old age. Courtesy E.F. Smith Collection, University of Pennsylvania.

All that said, chemists still faced the brute facts of stoichiometry, which were ever more fully established in the 1810s and 1820s, and which made no sense unless there were indeed chemically irreducible packets of matter, of which each element had a characteristic relative weight. That is the chemical atomic theory. No one knew whether the molecule of water was HO, H_2O, HO_2, or some other pattern, and this meant that no one knew whether the relative weight of the atom of oxygen relative to that of hydrogen was 8, or 16, or 4, or some other integral multiple or integral divisor. Such uncertainty sapped the strength of the early atomic theory. However, once the laws of stoichiometry were established, no one seems to have doubted that some sort of irreducible parcels of elements, whether you call them atoms, or proportions, or equivalents, must exist. One could posit certain simple molecular formulas, for instance of water, carbonic oxide, and ammonia, even just as a provisional convention rather than as an empirically determined fact, and from these formulas use the measured combining weights to determine relative atomic weights. In fact, virtually every chemist after Dalton did exactly that, including putative atomic skeptics such as Davy, Gay-Lussac, Wollaston, Jean-Baptiste Dumas, Marcellin Berthelot, and Wilhelm Ostwald. And atomic theory had great heuristic and expository value, even for those atomic weight systems that were later superseded.

Dalton's earliest biography, published the year after Dalton's death but still well worth reading today, was written by the Scottish chemist George Wilson. In a contemporarily perspicuous as well as dramatically prescient passage, Wilson wrote (*29*):

> To the student who, with difficulty, has been struggling to form a clear conception of equivalents, proportions, and the like, which, after all, he apprehends only as shadowy, ponderable masses of equal value, the passage is like that from morning twilight to full day, when he grasps firmly the idea of different atoms like separate spheres, each a perfect whole, possessing a definite and ponderable weight. The movements and relations of the equivalent atoms can thereafter be as readily followed in thought by the chemist in his speculations, as those of suns, or of planets and their satellites, by the astronomer, in the calculations which the science of the heavenly bodies demands. Nor is any revelation which chemistry seems destined to undergo, even should it bring about the decomposition of all the so-called elementary bodies, likely to lessen, or even much to alter, the value of the atomic hypothesis, considered as a device for inculcating chemical truths.

It was perhaps Dalton's most brilliant insight to look beyond all the pitfalls and doubts, and recognize a way to move forward into the realm of the invisibly tiny. In fact it was his philosophical naïveté, if one can call it that, that helped him along this path. W. V. Farrar commented (*30*), "There was never anything shadowy or metaphysical about his atoms; they were (in Newton's phrase, which he often quoted) 'solid, massy, and hard'; too small to see, but very real." Similarly, Dalton's friend Angus Smith wrote in his biography of Dalton (*31*), "We find no scientific man holding the idea [of atoms] with such firmness; to others it was a theory, to Dalton it was a fact, which he could not conceive otherwise. … We appear to be entirely removed from the region of speculation when reading his words." Smith testified that Dalton always exhibited "a great rapidity of reasoning, a direct passage from premise to conclusion without fear, as if more than usually persuaded that true reason could not misguide him. … He drives on like a new settler, and clears the ground before him, leaving it rather rugged, it is true, nonetheless it is resolutely cleared." This view of Dalton is not inconsistent with Davy's, but it is much more positively phrased, and is a fairer assessment.

We conclude with perhaps the best brief analysis of the connection of Dalton's personality and character to his science, which was written by George Wilson (*32*):

> Such was Dalton: a simple, frugal, strictly honest and truthful man. For the independence, gravity, and reserve of his character, he was, doubtless, much indebted to his birth as a Cumberland yeoman, and his long connexion with the Society of Friends. The individuality of his nature showed itself in his great mathematical capacity, his thorough self-reliance and power of patient, persevering work, the native clearness of his intellectual perception, and the extraordinary power of fearless

generalization which he brought to bear upon what nature unfolded to him. In the latter quality, in particular, he excelled every one of his scientific contemporaries.

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Chapter 5

The Chemistry of Lucrezia Borgia et al.

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According to folklore, poison was a tool of statecraft for women in power during the European Renaissance. The purpose of this paper is to examine some of the materials and techniques that might have been available to these women, as well as ways in which these poisons may have been deployed. It is concluded that there is no irrefutable evidence that the poisonings discussed herein occurred, but arsenic was probably the most reliable and flexible poison available to them, and that techniques existed at the time to engineer arsenic poisons for various political needs.

The title of this paper was chosen to pinpoint time, place, and topic—the time is the Renaissance, the location is the Mediterranean, and the topic is poison as a tool of statecraft. This recognition, of course, stems from the legends surrounding Lucrezia Borgia (1480–1519). Traditionally, Lucrezia is painted as an evil, licentious, corrupt poisoner. Yet, under close examination these perceptions do not bear up.

According to Sarah Bradford, Lucrezia's biographer, Lucrezia was not particularly evil. She was cultured and well educated (*1*), and there is every indication she enjoyed the role of wife and mother. She protested the annulment of her first marriage (*2*) and tried to protect her second husband from the attack that killed him, which was orchestrated by her brother (*3*). She gave birth to some eight children and wrote of her joy at their deliveries and agony at their deaths (*4*).

The charges of licentiousness must also be evaluated in context. She had lovers (*5*) and probably an illegitimate child (*6*), but such things were not unusual at the time. She herself was born out of wedlock (*7*), and still her presence at the Holy See was celebrated. In a Vatican mural she is portrayed as St Catherine (*8*). Likewise, the claims of corruption are suspect. Her father, Pope Alexander VI, was

In Characters in Chemistry: A Celebration of the Humanity of Chemistry; Patterson, G., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

quite corrupt by modern standards (*9*), so he would have recognized corruption when he saw it; nonetheless, he appointed Lucrezia Governor of Spoleto—in a legitimate, governing, administrative sense (*10*)—and there is evidence he trusted her to take official charge of the Holy See in his absence, making her the first and only woman to have had that responsibility (*11*). As for the question of her use of poison as a political tool in these positions, there can only be suppositions. Although there appear to be credible reports that Pope Alexander VI and Lucrezia's brother, Caesar, as well as other politicians of the day, did indeed employ poison as a method of overt or covert execution (*12*)—and Lucrezia was rumored to possess a ring for dispensing poison drops (*13*)—the Vatican historian at the time, Johann Burchard, who reported everything, including clothing-optional events attended by Lucrezia and the Pope (*14*), purportedly said nothing about Lucrezia poisoning anyone (*15*). So either she wasn't an evil, sneaky poisoner—or she was a very good one.

Nevertheless, even without direct evidence that Lucrezia actually used poison as a political device, it might be supposed the weapon was available to her based on the reported actions of other powerful Renaissance women. Take, for instance, Caterina de' Medici (1519–1589). Caterina de' Medici was married at age fourteen to Henry, second son of the king of France, though she was not of royal blood (*16*). She was a Medici, a member of a powerful and wealthy family in Florence but one that gained its stature by banking and trade, not divine right. For this reason, some in France looked down on her, and may have referred to her as the daughter of a shopkeeper (*17*). Yet the marriage was allowed to go forward because Henry was not the next in line for the throne, so he should have not been king, and Caterina not queen (*18*). However, one day the Dauphin, who was in line for the throne, called for a drink of water from a countryman of Medici, a courtier from Italy. He drank and dropped on the spot. He died a few days later—and Caterina de' Medici became Queen of France (*19*). A book with information on poisons was found in the courtier's room, and he confessed—under torture—which does not prove anything (*20*). Considering the tortures of the day, all but the insane, faced with the same, would probably confess to killing the Pope—even if he stood right in front of them. So was Caterina de' Medici involved? Maybe yes, maybe no. Maybe we will never know. Could she have been involved? Definitely.

Caterina de' Medici had an interest in alchemy, and for good reason (*21*). Her family of shopkeepers did not mind getting their hands dirty and they were interested in any technology that might turn a profit. As such, they had a keen interest in alchemy. A panel in the studio of Francesco I de' Medici is a detailed depiction of an alchemical workroom (*22*), and Cosimo de' Medici was a patron and practitioner of alchemy (*23*). A piece of glassware called the Florence flask is still found in every well-equipped chemistry laboratory (*24*).

Though the stated goal of Caterina de' Medici's alchemy was personal care products, and to this end, she traveled with a retinue of "perfumers (*25*)," we may note that the equipment required by the perfumers could easily be perverted to more nefarious alchemy (*26*). Medici's biographer, Leonie Frieda, paints a sympathetic picture of this "great prince and . . . great woman (*27*)," but does not hesitate to note the queen's practice of politics by poison (*28*). Moreover, Medici was no shrinking violet. She had ten children and outlived all but two (*29*).

Likewise Caterina Sforza (1463–1509) was a virago (*30*), that is, a woman with attitude. In Elizabeth Lev's well-documented chronicle of Sforza's life, she tells of Sforza galloping across the Tiber, seven months pregnant, and pointing her cannons at the Vatican (*31*). In another instance Lev tells how Sforza had to confront rebels who had killed her husband and were holding her children hostage. When the rebels threatened to kill her children she allegedly appeared at the battlements and said something to the effect of "Do it! I have equipment to make more . . ." and lifted her skirts to illustrate her point (*32*). Apropos of the current topic is the story of Sforza's altercation with Pope Alexander VI, Lucrezia's father, in which she supposedly attempted to assassinate the Pope by sending him a document impregnated with poison (*33*). The couriers confessed—but again, under torture (*34*). So did she do it? Maybe yes, maybe no. Maybe we will never know. Could she do it? Definitely.

Caterina Sforza, like Caterina de' Medici, may have discovered that being a woman was a good cover for alchemy (*35*). She, like other women of her day, was responsible for the health of her family, and there were plenty of reasons to have poisons in the medicine bag of the Renaissance Doctor Mom. Small doses of strychnine have reportedly been used to rid the body of intestinal worms (*36*), external applications of deadly monkshood have been used to treat fevers and pain (*37*), and arsenic is an antimicrobial (*38*, *39*) and could be used to treat skin ulcers (*39*, *40*).

In addition, Sforza, like Medici, made her own personal-care products (*41*), and there were reasons to have poisons in the makeup bag, too. Belladonna was used to dilate the eyes for beauty (*42*). Arsenic was used to bring a blush to the cheek—which worked because arsenic causes vasodilation of the capillaries at the surface of the skin (*39*). Sforza recorded some of her recipes in a book that was published posthumously as *Gli Esperimenti*: The Experiments (*43*).

The indication that these women had access to materials and techniques with which to manufacture poisons still begs the question: why would they? Why would these women consider poison a viable technique for achieving political ends? These were women in positions of power. At that time, persons in power had no problem ordering stabbings, hangings, beheadings, crushings, drownings, guttings, smashings, and rippings limb from limb to make their point. So why should something as complicated as poison be added to the list?

There may be several reasons worth considering (*44*). First, at the time, poison was accepted as a civilized form of assassination, and in a way, it was. There is a modern cultural perception that the use of poison is somehow dishonorable, but given the alternative methods of the time, poison was not the worst choice. Socrates was given poison so he could die a dignified death. Furthermore, what is capital punishment by lethal injection if not poisoning?

Secondly, poison offered the option of surreptitious execution. There were times when the executioner would want to be identified for reasons of intimidation; however, there were other times when the executioner might want to remain anonymous, for instance to avoid vendetta. In these cases, poison might be recommended.

Furthermore, poisons could be designed for the application. Sometimes a fast-acting poison might have been required so the victim could not run for help or broadcast their victimization. Sometimes a slow poison might have been desired so the poisoner would have a chance to exit before the poisoning was evident. Sometimes a dry poison might be preferred for sprinkling on food; at other times a soluble poison might be needed if drink was the vehicle. Additionally, if the intended victim refused to eat or drink, poisons would be needed that were compatible with alternative modes of delivery.

Did the need for this variety in poisons necessitate a pantry of exotic plants and preparations? One objection to the validity of these tales of poisonings is that the practitioners would have needed the skills, materials, and equipment of a modern pharmacologist (*45*) to achieve their end with the appropriate means. Yet perhaps they were able to design all of these poisons with technology and materials within their grasp. Perhaps all these variations on the theme could be accomplished by one element. Perhaps everything points to arsenic.

From the chemical perspective, there may be some justification for this idea. To begin with, arsenic works. Once ingested, it binds to sulfur, denatures proteins, and inactivates enzymes (*46*, *47*). Arsenic disrupts adenosine triphosphate (ATP) production through several mechanisms (*48*, *49*). Moreover, its activity as a poison was well known at the time. It had been used as a rat poison since at least Chaucer's time and was known to be able to kill really big rats (*50*). Furthermore, arsenic was available. Arsenic is about as abundant as tin (*51*) in the Earth's crust and is found in volcanic fields (*52*), such as those in Italy (*53*).

Additionally, the ore is relatively easy to identify by the color of the sulfides. Orpiment (As_2S_3) is yellow and realgar (As_4S_4) is red (*54*). While these colors are muted in the unpolished ore, the ore is still recognizable because it has a distinctive odor (*55*), which is said to resemble garlic. To test this property, a sample of arsenic ore was obtained from Getchell Mine, Nevada. The ore was washed, dried, and compared to a similarly treated sample of non-arsenic mineral. The arsenic ore had a definitely different, strong odor. This odor may originate from compounds such as sulfides and organoarsines (*56*), although the literature is not clear on this point. The dearth of information may be due to the difficulty of quantifying the sensation of smell or the lack of volunteers for experimentation. Regardless, the odor is unique enough that this author was able to train her dog to find the ore in a pile of debris.

Pure arsenic, a metalloid, is not easy to isolate, mainly because it is so reactive it tarnishes in air (*57*). Fortunately (or unfortunately, depending on point of view) the pure material is not necessary to make poison; the actual poison is the tarnish. Traditionally this material is called white arsenic or arsenic trioxide (*58*), although the chemical formula has been judged to be As_4O_6. Above 800 °C As_4O_6 dissociates to As_2O_3, which is said to have a structure similar to N_2O_3 (*59*). The oxide can be easily derived by roasting the ore in air (*60*) and may sometimes be harvested from the flue of copper-smelting operations as arsenic is often found in conjunction with copper in ore (*61*).

Another reason arsenic might have found special favor as a Renaissance poison is that arsenic poisoning would have been easy to disguise. Arsenic trioxide is said to be tasteless (*62*) (the odor was tested in this study, but not the taste) and the symptoms—headache, confusion, diarrhea, drowsiness, vomiting, bloody urine, cramping muscles, stomach pain, and convulsions (*63*)—resemble malaises common at the time: cholera, malaria, flu, or poisoning from bad food. The sufferer might also experience a sore throat because arsenic trioxide is weakly acidic in aqueous solutions (*64*). (See equation 1.)

$$As_4O_6 + 6H_2O \rightarrow 4As(OH)_3$$

$$H_2O + As(OH)_3 \leftrightarrow [AsO(OH)_2]^- + H_3O^+ \quad K = 6 \times 10^{-10} \quad \text{eq (1)}$$

The one possible distinguishing characteristic—that arsenic poisoning is said to cause garlic breath—should not have been an issue: garlic is native to Italy and was used for flavoring and medicines at the time. Garlic breath in Italy would not have been uncommon.

Then again, there are some problems with the use of arsenic trioxide as a poison. Given its solubility in water, 17 g/L (*65*), and its LD_{50}, 14.6 mg/kg (oral rat) (*66*), a 70 kg victim would have to drink around 50 mL of saturated solution or eat about a gram of solid to have a reasonable chance of dying, if we assume ideal conditions such as pure samples and pure water as a solvent. So does the solubility problem do away with the legend of drops in Lucrezia's ring? Perhaps not. Paracelsus (1493–1541) flourished about the same time as Lucrezia and was reported by Partington (*67*) to have produced potassium arsenate, which Paracelsus found mixed with alcohol. Fowler's solution, an eighteenth-century invention, contained arsenic rendered soluble by boiling in alkali to form potassium arsenite, $KAsO_2$, and kept in solution with potassium carbonate (*39*). Caustic solutions were certainly known to Lucrezia and her ilk as they used lye in laundering (*68*). The toxicity of the oxyanions is also found to be very close to the toxicity of arsenic trioxide (*69*).

Then what about variations on the theme? Could arsenic be engineered to produce a fast death or a slow death or fashioned for alternative modes of delivery? Possibly.

If the victim's relatives were knocking at the Castello door and the poisoners wanted a rapid demise, arsenic could be mixed with an organic stimulant that could pump it through the system. Belladonna might be a good choice as it causes increased heart rate among its other symptoms (*70*). Of course, the use of an herbal potion to augment arsenic begs the question: Why not just use the herbal poisons to begin with? Monkshood, cyanide, belladonna, and strychnine are all very deadly and their activities were well known at the time (*71*).

In truth, the plant poisons were used on occasion, no doubt, but the use of plants as poisons had its own set of issues. Both plants and arsenic have to be collected, separated, and concentrated, but while the oxide of arsenic can be stored in essentially any container and kept indefinitely, organic materials must be stored carefully to keep them from rotting (they are, after all, organic). Extracting and concentrating the active ingredient without destroying it could also be trickier for the plant poisons. Most chemists have fond memories of undergraduate organic chemistry lab and can attest to this truth. By contrast, arsenic could be collected by throwing the ore in a hot fire, a much more robust process.

Plant poisons could also be a bit too obvious if the poisoning was not to be public. Plants tend to have unusual odors and tastes (*72*), whereas arsenic was either odorless or had a residual garlic-like odor. As we have stated, arsenic poisoning resembled other illnesses of the day whereas plant poisons could display diagnostic symptoms. For instance, strychnine can cause contractions in the facial muscles that result in a distinctive death mask (*73*). In addition, the dosage necessary to guarantee death with herbal poisons was also often the quick-acting dosage, which would limit its utility in clandestine attacks. On the other hand, arsenic could be given in a series of smaller doses, producing a subtle form of poisoning characterized by weakness, nausea, vomiting, weight loss, and eventual death (*74*).

So if our second variation, a slow death, was desired, chronic arsenic poisoning was certainly a candidate, but what about slow death with one dose? This period of history preceded the invention of time-release formulations; nonetheless, the Borgias were reported to have their own secret poison called Cantarella, which was said to be (*75*)

> . . . a brilliant white, slow acting venom, that was pleasant to the taste [and that] did not overwhelm a victim's vital forces by a sudden, energetic action. Instead, it worked to insensibly penetrate the veins, with a slow but deadly effect.

Although the exact formulation, if there was an exact formulation, may never be known, there is a species of beetle, the blister beetle, which is indigenous to the area and might have been the undisclosed ingredient. Apparently a couple of these creatures in a bale of hay will kill a horse (*76*, *77*). The compound cantharidin (see Figure 1) has been isolated from the beetles and blamed for the activity of their secretions, which, taken internally, kills by causing lesions (*78*).

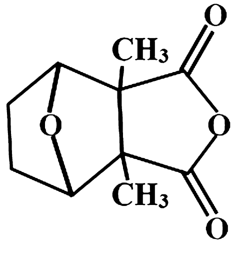

Figure 1. Cantharadin.

Mixed with a little arsenic for good measure, such a compounding should cause a slow but certain death. It is clear the beetle had been identified by the time of the Renaissance because it was used, in very small amounts, to make an aphrodisiac called Spanish Fly (*79*).

However, fast or slow, the mode of delivery for the methods addressed so far continues to be ingestion with food or drink, but when someone failed to respond to an invitation to dinner, an alternative method might be required. In this author's investigation, none of the legendary methods seemed to lend themselves to poisoning at a distance until this process, reportedly used by Caesar, Lucrezia's brother, presented itself. In the procedure a strong dose of arsenic was administered to a boar and as soon as the poison took effect, with accompanying convulsions and frothing, the boar was hung up by his heels and any and all excrement collected (*80*). To try to understand why such a cruel method might have been employed, the literature on the biochemistry of arsenic was researched, and it was found that arsenic is metabolized in the mammalian body by methylation: the body turns inorganic arsenic into compounds such as dimethyl arsenious acid (*81*) and dimethyl arsenic acid, also known as cacodylic acid (*82*). Although methyl arsenates are reported to be less lethal than inorganic forms of arsenic (*83*, *84*), the advantage Caesar may have stumbled on is that methylated arsenicals are more soluble in ethanol (*85*), which arsenic trioxide really isn't (*86*). In other words, these compounds would be soluble in wine—which could be important: a precipitate on the bottom of the wine glass might give away the game. Germane to alternative modes of delivery, solubility in ethanol means methyl arsenates would also be soluble in tinctures: the ethanol extracts used as medicines, such as laudanum—which opens up a new avenue for administration. What better cover for poisoning than to have the doctor do it? When a person is in physical distress and a doctor says "take this," most people take it. Given the success rate of doctors at the time, it is doubtful the death of yet another patient would be particularly suspicious.

Finally, there remains the matter of Caterina Sforza's poisoned letter. If the incident actually occurred, the document may have been steeped in some herbal mixture or the contamination of a plague victim, as legend would have it (*87*), but these two methods should result in a suspiciously odd-looking and smelling document. On the other hand, if the paper were soaked in an alcohol solution of arsenicals, then left to dry, the resulting paper would probably resemble any other. How would the poison transfer to the Pope? Given the amazing number of times people touch their mouths, noses, and eyes in the course of a day, all lined with mucus membrane and ideal entrées into the body, combined with the minimized hand-washing habits during the Renaissance (*88*), perhaps the Pope could have poisoned himself in the process of document perusal. If the potency needed a little boost, perhaps a bit of blister beetle might be added to the mix.

As a last indication that arsenic might have been a poison of choice during the Renaissance, there is the report by a team of forensic toxicologists in the British Medical Journal that arsenic may have been used in the death of Francesco I de' Medici and Bianca Cappello (*89*).

According to historical accounts, there were political motives for Francesco's brother, who was present at the time of their deaths, to want them dead. Suspiciously, husband and wife died on the same day, hours apart, after suffering for eleven days with an illness that caused vomiting, intestinal distress, convulsions, and a sore throat. Samples obtained from viscera jars, one matched via DNA to Francesco I and the other thought to be Bianca Cappello, appeared to show toxic concentrations of arsenic in the soft tissue. If this were a chronic exposure from activities such as Francesco's alchemy, then samples of hair and bone should have shown elevated concentrations, but they did not. Even so, consideration must be given to the competing theory that they died—on the same day—from malaria. Evidence for the malarial parasite was also found, but malaria, in Italy, was fairly common at that time.

So did they die of arsenic poisoning? Maybe yes, maybe no. Maybe we will never know—which, actually, is our conclusion: when it comes to chemistry during the Renaissance, reality and legend may always be intertwined. Nonetheless, we believe there is value in the effort to identify the chemistry as practiced then—as in the compounding of poisons—with the chemistry as understood today to paint a better picture of Renaissance chemical knowledge. We also believe this effort would be improved by reenactments of historical chemistry with the equipment and materials available at the time. To this end, more explorations are necessary, both in the library and in the lab. Happily, no matter how difficult or convoluted the quest, this period of political and chemical history, like Lucrezia, will always be intriguing.

Acknowledgments

It would be remiss to not recognize Wikipedia.org. Wikipedia was not used as a reference for any information in this paper, yet we found this website to be very useful for following threads and developing directions. We wish to acknowledge this value.

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Chapter 6

Chemical Characters: Sir William Crookes (1832−1919)

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The flamboyant bearded and moustached appearance of the chemist, Sir William Crookes, was striking; his career from humble beginnings to the presidency of the Royal Society without academic or industrial tenure was unusual; to contemporaries Crookes's ability to investigate "anomalies" that led to fascinating revelations concerning cathode rays, the radiometer and ideas about the evolution of matter and chemical elements made him seem a sage. A great scientific journalist and elder statesman of science who was active at the bench until the day of his death, we shall find justification for calling him one of chemistry's most extraordinary characters.

The figure of speech, "chemical character", means more than a chemist who played a role in the great drama of chemistry; it refers to someone whose unique personality and career marked them as out of the ordinary. In this chapter, we take the example of the English chemist William Crookes. His flamboyant bearded and mustached appearance was striking, as dozens of surviving photographs and caricatures show; his career from humble beginnings as a tailor's son to the presidency of the Royal Society in 1913 – achieved without academic or industrial tenure – was unusual; to his contemporaries Crookes's ability to investigate "anomalies" that led to fascinating revelations concerning the radiometer, cathode rays, and ideas about the evolution of matter and chemical elements made him appear sage-like. A prolific scientific journalist and elder statesman of science

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ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

who was active at the bench until the day of his death, Crookes fully deserves being recognized as one of chemistry's most extraordinary characters (*1*).

Crookes (Figure 1) has figured less in the historiography of Victorian science than he deserves probably because his work was so inter-disciplinary. He was largely an autodidact who modelled himself on Hofmann, Faraday and Stas. During his long career he was able to make significant contributions to photography, chemistry, physics, agricultural science, public health, and scientific journalism. He had a talent for recognizing significance in apparently trifling experimental observations. Gifted with an indefatigable work habit, his scientific interests were eclectic, so that it is straitening to label him a chemist or even a chemical physicist. As he himself noted during a polemic with the biologist William B. Carpenter in 1871, he had published research on general chemistry, thallium, analysis, disinfection, photography, metallurgy, polarization, spectroscopy, photometry and astronomy. "In truth," he declared, "few scientific men are less open to the charge of being *a specialist of specialists*" (*2*).

Although widely recognized by historians of science for the brilliance of his experimental researches, as well as for his controversial support for spiritualistic phenomena, Sir William Crookes (1832−1919) earned his living principally as a science journalist and editor. He founded and edited the weekly *Chemical News* in November 1859, and he was also closely involved in the editing of the important popular middle-class *Quarterly Journal of Science* between 1864 and 1879. Both these journals were commercial successes, unlike *the Electric News*, a journal he modelled on *Chemical News* in 1875, that collapsed after only twenty weekly issues.

He was eclectic in his interests, ranging over pure and applied science, economic and practical problems, and psychic research, and this encouraged him to write for a variety of audiences. His diverse interests collectively made him a well-known personality within the late Victorian scientific community. Each of his brilliantly-illustrated lectures to the Royal Institution and his Presidential lectures to the Chemical Society (1887), the Institution of Electrical Engineers (1891), the Society for Psychical Research (1897), and the British Association for the Advancement of Science (1898) proved *tour de forces* and were widely reprinted or reported. Indeed, such was the world-wide furore over his 1898 British Association address, which was concerned with the desperate need to fix nitrogen to solve a perceived future world food shortage, that it was twice reprinted, as well as being reported in the world's newspapers.

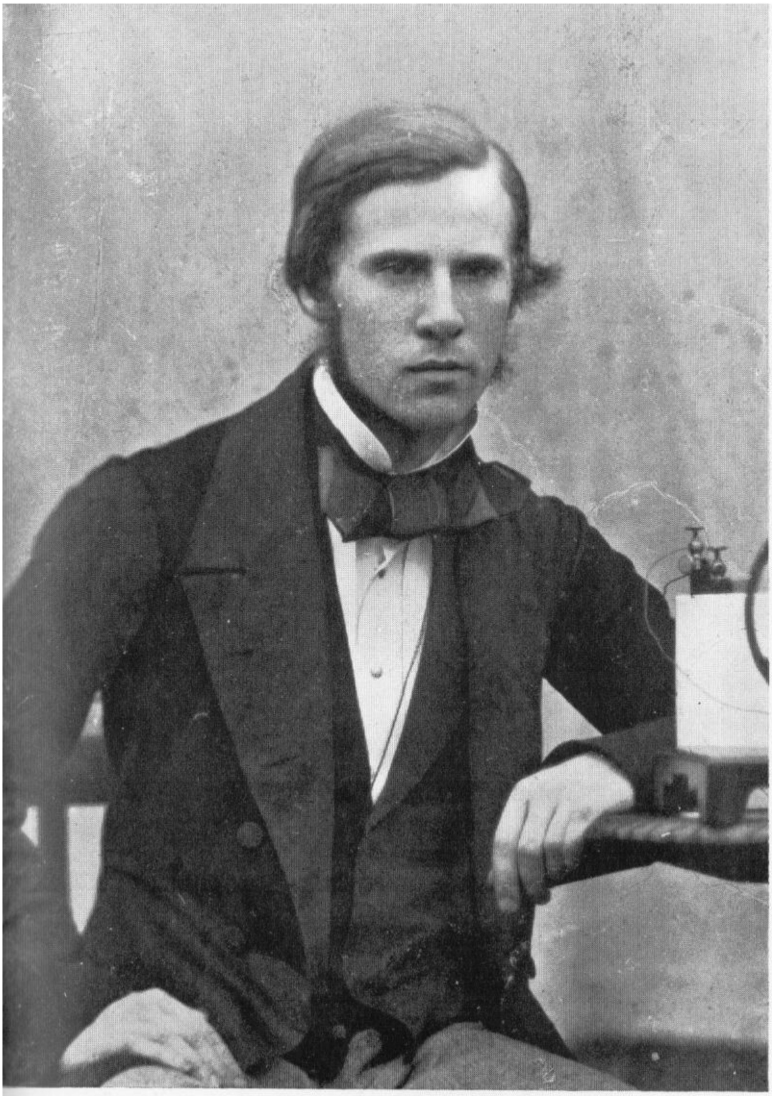
When the American literary historian Arthur Nethercot came to write a biography of Anna Besant in the 1960s he felt compelled to describe her complicated changes of attitude and career as *The Nine Lives of Anna Besant* (*3*). Crookes's career was, if anything, even more complicated since, whereas the sequence of Besant's career was made up from distinctly separate work objectives, Crookes's multiple activities were largely concurrent. In each of these activities Crookes became an expert and innovator.

*Figure 1. Sir William Crookes in 1903. Caricature by "Spy" (Leslie Ward) in Vanity Fair, **1903**, 21 May. (Reproduced by permission of Welcome Library, London.)*

The Photographic Chemist

Crookes was born on the 17 June 1832 in Regent's Street, London, where his father, a prosperous West End tailor, kept a shop. We know little about his childhood and education except that while retaining the Regent Street shop, the family moved to a large house in Hammersmith in the 1840s. In 1837, when Crookes was only five years old, the world first learned of the possibility that images of nature could be fixed chemically on glass and paper using lenses and chemical compounds. Crookes became fascinated by this new science of photography and began experiments on this new technology at an early age. He probably persuaded his father that there might be a commercial future in photography, provided one knew something about chemistry. Crookes would have been well aware as a teenager that, in 1845, the Royal College of Chemistry (RCC) had opened in Oxford Street, just around the corner from his father's tailoring business. It is not surprising, therefore, that at the age of 16, Crookes became a full-time student at the RCC, whose Director was Liebig's distinguished pupil, August Wilhelm Hofmann. Within a year, Crookes had won a scholarship that allowed him to continue his studies, and within two years he had become one of Hofmann's personal assistants (Figure 2). It is interesting to note that although the trajectory of Hofmann's research was organic chemistry, Crookes remained largely dedicated to developing his skills as an inorganic chemist and metallurgist. Although the RCC produced a few academic chemists (such as William Odling, Charles Bloxam and Edward Divers), the majority of its students became industrial chemists or consultants. Crookes was, therefore, by no means unusual in deciding to plan his career as an independent consultant specialising in photographic science. On the other hand, he was one of the very few RCC graduates to make a name for himself outside academia.

At the RCC Crookes developed a close friendship with another of Hofmann's personal assistants, John Spiller, who had also become extremely interested in photography. As their correspondence shows (*4*), the two chemists spent weekends and holidays together experimenting with different cameras, papers and chemicals in order to improve their photographic techniques. Their collaboration continued after Crookes left the RCC in 1854 to become an assistant at the Radcliffe Observatory in Oxford. Meanwhile, Spiller, who had left the RCC in 1853, joined John Percy in metallurgical research at the Royal School of Mines and the Woolwich Arsenal before he entered the dyestuffs industry. Crookes once told Spiller that one could either opt to go for a European reputation and appear to posterity as mankind's benefactor but never have any money while living; or make money and be accused of lowering the dignity of science by turning it to a trade. Crookes was to choose the latter path even though the position at Oxford gave him opportunities for an academic career. One of the reasons he failed to take a degree was undoubtedly the fact that he would have had to learn Greek and bolster his limited knowledge of Latin in order to matriculate at the University of Oxford. (He registered at Magdalen Hall but did not pursue a degree.)



WILLIAM CROOKES AS HOFMANN'S ASSISTANT, 1850.
ÆT. 18.

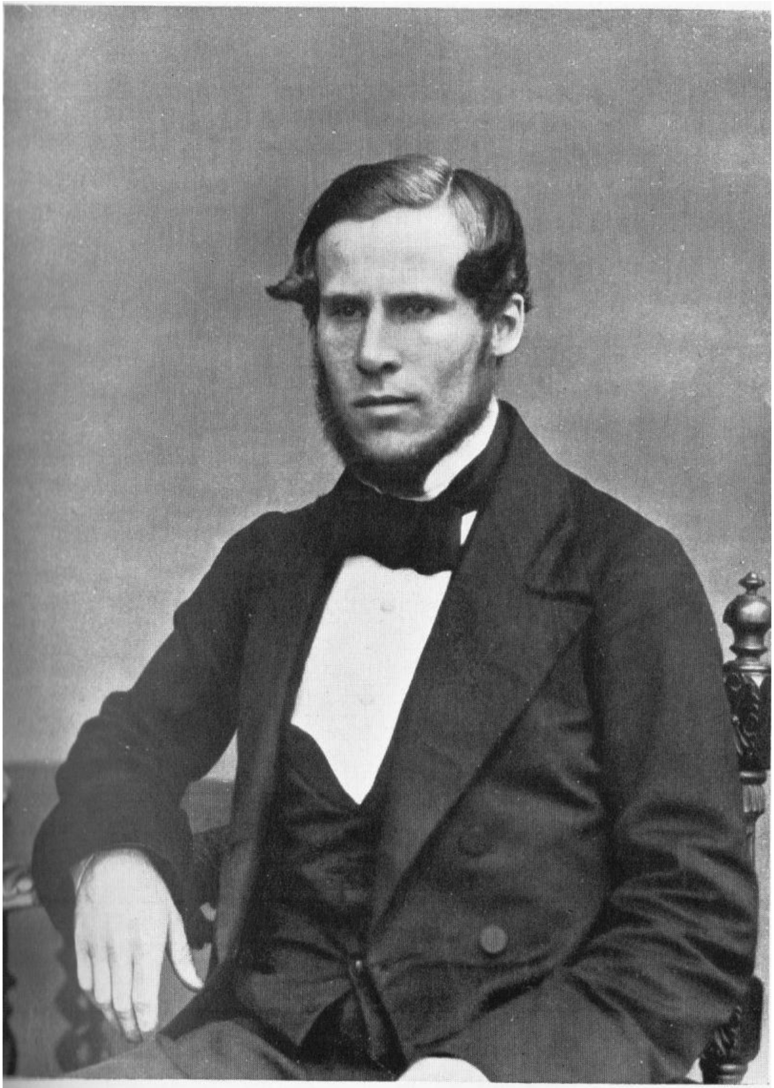
Figure 2. Crookes at age 18. (From D'Albe, ref. (23), p. 22.)

At the Radcliffe Observatory Crookes formed the sole member of the Meteorological Department; his job was to develop instruments that would provide an automatic hourly record of changing weather conditions. This was part of a larger project to see whether astronomical events influenced the weather. Although self-recording instrumentation was not new, Crookes made considerable improvements to the technique, chiefly by using waxed photographic paper. His techniques were subsequently adopted by the Royal Society's observatory in Kew Gardens and formed the substance of Crookes's first book in 1857 (*5*).

After only a year at Oxford, Crookes resigned and took up a new career as a schoolteacher in Chester where he had the opportunity to design and build a chemical laboratory. The school was actually a training college for pupils who intended to become teachers in the National Schools that the Anglican church had established since the 1820s. Later reports from some of Crookes's pupils suggest that he proved a fine teacher. However, the position was again short term. Crookes fell in love and because the College would not employ married teachers, Crookes abandoned the post in 1856 when he married Ellen Humphrey. He had evidently met her (a Durham girl) while he was spending his weekends in Liverpool where he was carrying out experiments to photograph the moon and other celestial objects using the telescope that had been established on the harbor front. His Liverpudlian contacts also led to membership of the country's first photographic society, the Liverpool Photographic Society, and an invitation to become the editor of its pioneering journal. (Until the appearance of journals published by photographic societies, photographic innovations were reported in the antiquarian monthly *Notes & Queries*) (Figure 3).

Thus, by 1856, Crookes seems to have had two choices to further his fortunes. One was to pursue astronomical photography; the other was to become a photographic journalist and editor. Typically, Crookes did both. Either way, he and his wife decided to make their home in London. It is worth noting that had Crookes died before 1860 he might have been remembered solely as pioneer of photography and photographic editor.

Overall, Crookes made four fairly significant contributions to photography: the development of the dry plate through the use of deliquescent chemicals; the recycling of used collodion; the development of waxed paper techniques; and the determination of spectral sensitivities of chemically-saturated papers. He brought to photography the experimental and analytical skills that he had absorbed at the RCC under Hofmann to which he added a strong grasp of physical optics. For a decade Crookes was a well-known expert in photography, highly respected for his scientific contributions to the subject, especially for his pioneering lunar photography which he exhibited and published with the Royal Society in 1857. It is a great irony that none of these achievements were cited by Alexander Williamson when he proposed Crookes for membership of the Royal Society in 1863. By then, such achievements had been surpassed by Crookes's discovery of thallium and, at a time when there was intense competition at international exhibitions, it was important to declare the discovery as a British chemist's triumph.



WILLIAM CROOKES, 1856.
ÆT. 24.

Figure 3. Crookes at the time he was best known for work in photography. (From D'Albe, ref. (23), p. 32.)

The Editor, Printer, and Publisher

Some would argue that Crookes was first and foremost a journalist who helped mould public opinion on water purity, sewage disposal, food production, and adulteration. As we have seen, Crookes fell into journalism when he became editor of *The Journal of the Liverpool & Manchester Photographic Society*. Within months of his appointment he found himself secretary of the London Photographic Society and in charge of editing its journal as well. Since the latter was a full-time appointment, he gave up editing the Liverpool journal, only to find himself sacked from the London society. Although the reasons were never made public, it appears that he was accused of mis-appropriating the society's funds and using them for non-society purposes (*6*). This must have been a devastating blow to such an ambitious man. But he quickly fell on his feet when Cassell's, the publishing house, decided that photography had become so popular that a weekly journal devoted to the subject would be a viable commercial proposition. Crookes was asked to be the first editor of this *Photographic News* in September 1858. Initially, Crookes made a great success of this, but then things went awry and he was sacked for the second time in December 1859. Crookes immediately sued Cassell's for wrongful dismissal. Crookes lost his case in February 1860 on the grounds that he had published inflammatory remarks against his previous employers at the London Photographic Society that were detrimental to Cassell's commercial interests in gaining their members' readership; and that he had founded a rival journal without the proprietors' permission. This was, of course, *The Chemical News* which Crookes had launched as a weekly publication on 10 December 1859.

These experiences with three photographic journals reveal much of Crookes's impetuous character as a young man. Overconfident in his own abilities, he overreached himself, leaving himself covered in ignominy rather than glory at the Photographic Society of London, and at the offices of the *Photographic News*. This was an aspect of Crookes's character that would flare up again and again throughout his life. His career as a photographic chemist having collapsed, Crookes turned instead to *Chemical News*, and he used this successfully to build his reputation as an analytical chemist. *Chemical News* was not to be the last of his editorial ventures. From 1863 to 1879 he was also the editor of the *Quarterly Science Review*, a handsome magazine that was modelled on the great Victorian literary periodicals. It was to provide Crookes, and his many distinguished scientific contributors, the opportunity to provide popular, authoritative and well-written accounts of contemporary scientific developments, as well as a platform to help mould public opinion on the great civic problems of the day – water purity, sewage disposal, adulteration and agricultural productivity. The ownership of *Chemical News* was to underline the links between science and commerce that remained the hallmark of his career.

The Chemical Consultant and Analytical Chemist

While *Chemical* News was to provide the foundation of Crookes's earnings for the remainder of his life, he continually supplemented it with income derived from consultancies and the publication of chemical handbooks. Among the latter were translations of German technical manuals on the new aniline dyestuffs, the techniques of calico printing, metallurgy and industrial chemistry. Much of his salary also came from advice that he provided on sanitary matters such as the disposal of town sewage and water purification. *Chemical News* gave him a weekly editorial platform to publicise urban problems: adulteration, water purity, sewerage. These were concerns that he shared with Liebig. Although he never met the great German chemist, interestingly he became a close friend of Mrs Tweedie who was a daughter of Emma Muspratt, Liebig's god-daughter (*7*).

Perhaps the best-known of his analytical handbooks during his lifetime was the *Select Methods of Chemical Analysis* (1871) which quickly became an essential reference book in the libraries of public analysts. His chemical education had given him marketable skills. Not surprisingly, Crookes was one of the founding fathers of the Society of Public Analysts in 1874 whose meetings were initially reported in *Chemical News* before the publication of its own journal, *The Analyst*, in 1876. He also edited texts that were relevant to the commercial analysts, and acted as assayer or analyst for industries. Historians can trace the development of professional chemical associations like the Society for Public Analysts, the Institute of Chemistry and the Society for Chemical Industry through the editorial support that Crookes gave in *Chemical News*.

The Spectroscopist

One of the devices that Crookes invented during his photographic researches into the effects of different wavelengths of light on photographic plates was the "spectrum camera". Except that it did not use a prism to separate light rays, this was to all intents and purposes a spectroscope. Consequently, when Bunsen and Kirchhoff announced in 1859 how their spectroscope had enabled them to detect the presence of the two previously-unknown elements, caesum and rubidium, Crookes was well placed to take up spectroscopy. Indeed, other chemists who wished to take up spectroscopy came to him for advice, while instrument-makers asked him for design specifications. Crookes himself immediately used the instrument in the hope that, like Bunsen, he would be able to find yet other unknown elements by searching through his private collection of minerals and samples. He was rewarded in 1861 when a green line flashed into view while he was using samples of selenium ores that he had used when he had investigated selenium salts at the RCC in 1850. After a frenzy of research activity, he was confident of his findings and named the element thallium in May 1862. The following month he exhibited samples of the new metal at the International Exhibition that was being held in South Kensington. Unfortunately, his plans for a leisurely and careful investigation of thallium were thwarted when the French chemist Claude-Auguste Lamy (1820−1873) announced that he had also isolated the element.

As so often happened in cases of simultaneous discovery, the resulting European controversy over priority rapidly acquired nationalistic and patriotic overtones. British chemists, led by Alexander Williamson, rushed to protect Crookes's honour by getting him elected to the Royal Society in 1863. This honour also gave Crookes a safety net: thallium was Crookes's property and (at least in British chemists' eyes) Crookes had the sole right to investigate its detailed chemistry. This was where Crookes's talent for accuracy and precision was to be fully demonstrated. He was to spend a decade preparing thallium compounds and describing their chemical properties. More significantly, and using Jean Servais Stas as his model, he determined thallium's atomic weight. Consequently, he took great pains to purify his reagents, to calibrate his weights, and to use an extremely sensitive Oertling balance which he mounted in an iron case that could be exhausted of air. In this way, weighings were to be made at reduced pressures and reduced to a vacuum standard in order to correct for air buoyancy. The final determination of an atomic weight of 203.642 was not published until 1873. Crookes took due note of the fact that the figure was not a whole number; neither was it close to 203.5 or a multiple of 0.25. Like Stas, Crookes appeared to have demolished Prout's hypothesis that elements were "severally multiples of the atomic weight of hydrogen". He was soon to change his mind.

It was while operating his balance in a partial vacuum that Crookes noticed an "anomaly"; namely that the equilibrium of the balance was disturbed by slight differences in temperature between his samples. In particular, he noticed that warmer bodies appeared lighter than colder ones. This could not have been caused either by the condensation of vapour on the cooler body, or by air currents surrounding the hotter body, since the prevention of these effects was the purpose of using a strong vacuum in the first place. What then was the cause? In later life Crookes always advised aspiring scientists to be on the lookout for anomalies. As for the present oddity, he felt sure he had stumbled upon something of major significance, indeed of cosmic significance, for he initially believed that he had found a "sign-post" linking heat and gravitation. This brings us to another of Crookes's "lives" because his concurrent commitment to investigating psychic phenomena, while determining the atomic weight of thallium, undoubtedly interacted in a creative way.

The Spiritualist

Crookes's interest in anomalous phenomena also accounts for his investigation of spiritualism. By 1860 Spiritualism was a well-established religion that had spread through the grapevine of domestic servants and theatrical demonstrators through all levels of Victorian society (*8*). Although scientists were often accused by partisans of the movement of wilfully refusing to investigate the claims of psychic phenomena, it was in principle a very scientific religion in the sense that spiritualists wanted their phenomena tested, experimented with and, of course, verified. This means that Crookes's initial interest in spiritualism was entirely legitimate and part of his current scientific research. Crookes was one of several scientists who approached the wonders of mediumship with an open mind, even if the death of a younger brother in 1867 meant that he had a pious hope that life after death could be experimentally validated. Was his interest in psychics silly and credulous? Not necessarily, since he was sure unknown forces existed and were waiting to be discovered. The fact that mediums perpetuated fraud did not disprove the existence of strange forces.

As one of the greatest experimental investigators of the nineteenth century, Crookes had impeccable scientific credentials and, armed with a supreme confidence in his own critical powers, he expected readers to accept his word. In July 1871 he announced that he was engaged in the experimental investigation of a new force, the "psychic force" which he had detected as a natural power of the astonishing Scottish−American medium, D. D. Home. In one of several experiments with this medium, one end of a plank of wood was suspended from a spring balance whilst its other end just rested on the edge of a table. Home's fingertips were place lightly on the end of the plank before the fulcrum and, on asserting his "psychic force", a depression (*not rise*) of the spring balance was recorded by onlookers. Crookes attributed this depression not to any surreptitious movements on Home's part, but to a genuine flow of nervous energy, or "psychic force", from Home's body. He noted with approval that Home seemed exhausted by the effort of the experiment since this suggested that the principle of energy conservation had not been broken. The experimental conditions are seemingly well described, though much essential detail about lighting or the positions of the observers were not recorded in the published account in Crookes's *Quarterly Journal of Science*.

Other memoranda on Home's feats seem even more incredible:

> On one occasion I witnessed a chair, with a lady sitting on it, rise several inches from the ground... On three separate occasions I have seen Mr Home raised completely from the floor of the room, once sitting in an easy chair, once kneeling on the chair, and once standing up (*9*).

Whatever one thinks of Crookes's credibility here, the point to emphasize is the observation of lightness, or levitation, and their links with overcoming gravitation. Such extraordinary statements soon led critics to talk of "two Crookes's", one a rational scientific experimentalist; the other a gullible hunter of miracles. Faced by such a Janus, it is scarcely surprising that the Royal Society rejected Crookes's paper on Home, forcing him to publish it in his own journal. One leading critic, William Benjamin Carpenter, ranted against Crookes's split personality and asked why rational Crookes was unable to see that so-called spiritual communications came from *within* the individuals who supposed themselves (or pretended) to be in communication with departed spirits. Carpenter also made the point that although a scientist may have a reputable reputation in one field, he might be totally incompetent in another. Carpenter's point, which now seems very modern, was that it was not ability at chemistry or physics that was needed to investigate Home, but ability at psychics or psychology.

It was part of Crookes's character not to see any difference, and this fact goes some way to explain the apparently unsatisfactory nature of some of his testimony. He was not trying to hoodwink others when he failed to cite the names of witnesses: in modern science witnesses' names are not cited because, ever since the seventeenth century, the word and reputation of a gentleman was a sufficient guarantee of objectively observed phenomena. Or so Crookes believed. To state otherwise was as good as saying that he was not a gentleman. Perhaps if only Crookes's description of his experiments with Home had been at stake, his fellow scientists would have taken this point, but it was more difficult to give credence to his uncontrolled observations of a teenaged medium named Florence Cook. In 1872 Miss Cook began to materialize a spirit she identified as "Katie King". Florence sat under restraint behind a curtained-off portion of a drawing room to which there was (supposedly) no outside access. After some time "Katie would come out from behind the curtains dressed in white robes and talk with the assembly in very human fashion. She would eventually retire and after a further pause, the curtains were opened to reveal Miss Cook, still in her own clothes in her former position.

In December 1873 there was a scandal when a member of the audience grappled with the spirit and claimed that he had caught Florence in his arms. The matter was by no means as straightforward as this bald account may appear (*10*), but the outcome was that Crookes agreed to investigate Florence Cook's claims in his own home laboratory where conditions (he claimed) could be controlled. Two months later, to the surprise of many, Crookes reported that she was genuine and that he had had the privilege of seeing *both* Florence and the spirit of Katie together. This remains one of the most controversial episodes in Crookes's career and much ink has been spilled over it. Whatever the truth of the matter is (Crookes was guilty of fraud or gullibility?) it is clear that until the end of his life Crookes believed there was something in psychic phenomena. There is little doubt that for him personally the phenomena he had studied were indicative of the existence of a psychic force or power in the universe *and* the existence of intelligent beings of a non-human kind. But, until his wife's death in 1916, he never explicitly claimed that these intelligences were the spirits of the dead. Such a position is Swedenborgian (after the eighteenth-century Swedish visionary, Emanuel Swedenborg), or theosophical, theosophy being the religious-philosophical system founded by the rumbustious Russian Mrs Blavatsky in 1875. Crookes was to join the theosophical movement in the 1880s. There are several references to Crookes exorcising mediums of unpleasant demons and devils, and it would not be misleading to call Crookes a magician and occultist (*11*). His world was populated by much more than that traditionally accepted by other nineteenth-century scientists, or the average scientist of today. To Crookes the study of the occult (meaning the hidden world of nature) was a legitimate way of extending the limited ranged of phenomena studied by scientists.

What on earth has all this to do with Crookes's ordinary life as a practising chemist? Let us return quickly to the anomaly Crookes had found in his evacuated balance holding his thallium samples.

The affected balance acted as if it were repulsed by a force. If Home could influence gravity (and recall that he levitated besides depressing spring balances), might not there be a connection with the well-known fact that heat repelled (that is, lightened) objects? This seems to have been the way that Crookes responded to Home's astonishing powers and to the balance anomaly. With Home as his evidence, might he not be able to give a rational scientific explanation of the psychic powers of mediums and cap it all with an explanation of gravity.

Crookes decided to see whether the effect he had noticed with the evacuated balance (a repulsion) was also produced by mediums. If the two were associated, as he suspected, then any explanation which he could find for the balance's repulsion might serve to reduce a medium's mysterious powers to scientific principles.

Unfortunately, Crookes soon discovered that not only mediums, but *anybody*, could affect the balance. By 1875 he admitted ruthfully that he had been unable to detect "the slightest action exerted by my own, or any other person's hand which I could not entirely explain by the action of heat." Meanwhile, however, Crookes's erroneous hypothesis had led him to open up an immensely fruitful new area of research. Crookes found that, when a large mass was brought close to a lighter mass suspended in an evacuated space, it was either attracted or repelled. By mounting two pith balls on a pivoted horizontal rod in a tube attached to a mercury pump, the effect could be isolated and examined in detail. This isolation of the phenomenon under conditions in which it could be controlled and varied demonstrated Crookes's ability as an experimental scientist. In this instance, Crookes found that the attraction and repulsion was heightened by a decrease of pressure – an effect ultimately responsible for Crookes's wonderful adroit development of pumps and glass apparatus capable of producing a vacuum of the order of one millionth of an atmosphere. Without this technological innovation, electric light bulbs, X-rays and the electron would have not been discovered perhaps for another fifty years.

By 1873 Crookes had concluded that the movement of an enclosed and evacuated pith balance was produced by the repulsion due to radiation from a warm body (like human fingers). At first he concluded erroneously that because light also produced this effect, he had stumbled upon an example of the pressure of light expected according to a corpuscular theory. By the 1870s, of course, physicists usually subscribed to a wave theory. Consequently, Crookes's suggestion was viewed with scepticism, even though a pressure of light was a prediction by Maxwell's as-yet unaccepted electromagnetic theory. However, it was this working hypothesis that led Crookes in 1875 to construct a "light mill" or "radiometer" – a wonderful scientific toy which proved a financial boon to instrument makers and shop-window dressers (Figure 4).

In this fascinating instrument, Crookes had mounted four mica weather-vanes on a needle inside a sealed evacuated glass vessel. The vanes were free to rotate on the head of a vertical darning needle. The mica pieces were blackened on one side with their surfaces all facing in one direction. When the instrument was brought near any form of radiation the arms rotated with a speed roughly proportional to the inverse square of the distance between source and instrument. The rotation

In Characters in Chemistry: A Celebration of the Humanity of Chemistry; Patterson, G., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

usually occurred in a direction opposite to that expected if light pressure were the cause.

The design of the radiometer was simplicity itself, but the explanation of its action proved a very difficult and controversial one. The mechanism soon caught the attention of prominent British physicists like Osborne Reynolds, Peter Tait, Arthur Schuster, Clerk Maxwell and Johnstone Stoney. In 1876 Crookes accepted the latter's explanation in terms of the kinetic theory of gases according to which the motion was caused by the internal movements of molecules in the residual gas. If the mean free path of the gas is small compared to the dimensions of the vessel, molecules which strike the warmer black vanes will rebound with increased velocities and will consequently collide with and hold back any slower-moving particles that are advancing towards the vanes. In this way, a relatively large number of molecules will hit the cooler non-absorbent unblackened surfaces and prevent any rotation of the vanes. If the pressure is lowered sufficiently, however, there will come a point at which the mean free path of the molecules will be large enough to prevent compensation of the recoil effect. Rotation will take place with the blackened surfaces receding. Similarly, as Schuster showed, using Newton's third law of motion, if the radiometer is ingeniously suspended or floated on water, it will rotate in a direction contrary to the vanes – thus demonstrating that the radiometer effect must be due to an interaction between the vanes and the residual gas particles. This simple explanation did not satisfy Maxwell, who provided a much more complicated mathematical analysis that incorporated a tangential shearing effect as the *modus operandi*.

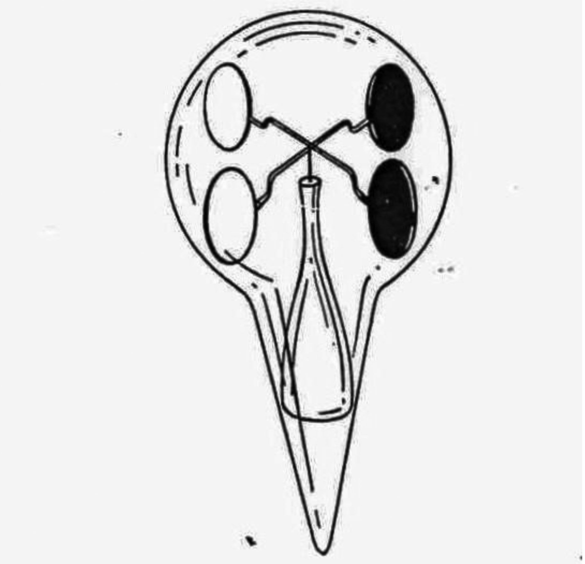
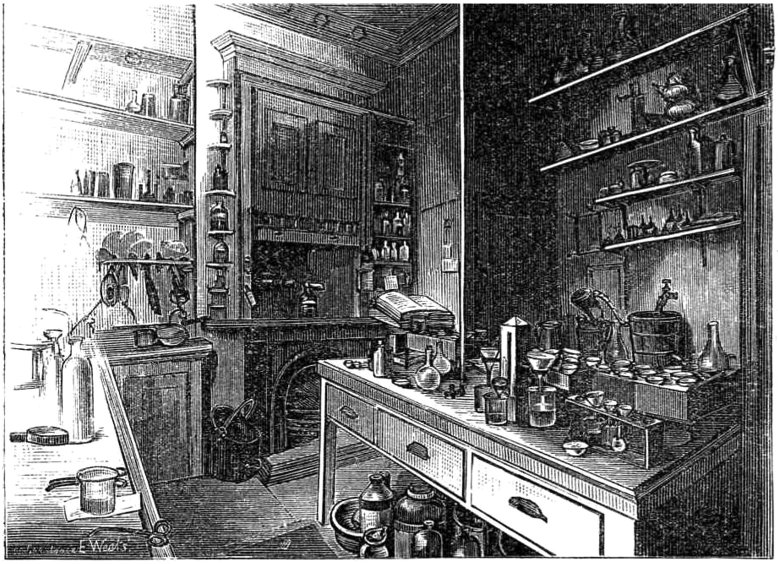


Figure 4. The radiometer. Four arms of fine glass are balanced on a needle point. At their extremities are pith or mica disks, each lampblacked on one side, the blackened surfaces all facing in the same direction. The balance stands inside a evacuated glass bulb. (From Brock, ref. (1), p. 214.)

The Electrician

Crookes, who was not a mathematical physicist, had little to do with the controversies surrounding the workings of the radiometer. What he did realize, however, was that the instrument provided a window into the behaviour of gas particles inside an enclosed space. Over the following ten years he brilliantly plotted the trajectories of these particles by incorporating electrodes into the radiometer and tracing the end points of their collisions by using a zinc sulfide screen. Spiritualism temporally tarnished his reputation, but it was rapidly restored and burnished by this brilliant research on cathode rays which he himself referred to as a fourth state of “radiant matter”. As a side issue of this fundamental research Crookes also developed the incandescent light bulb in competition with Edison in America and Swan in England. In 1880, Crookes’s laboratory assistant Charles Gimingham, who had developed vacuum pumps for Crookes, joined Swan’s research laboratories in Newcastle. At the same time, the publication of details of these vacuum pumps enabled Edison to engineer his own brand of incandescent bulb. The problem for all three entrepreneurs (and there were others in the field as well) was not the glass-blowing engineering, but to find a stable material for the filaments. Crookes’s own solution was to use a horseshoe-shaped carbon filament. He began making light bulbs in his own factory in Battersea and used them to light his own home in 1880, the power being generated from a gas engine that he housed in the basement (Figure 5). Unfortunately, Crookes could not compete with Edison, or the combined power of Edison−Swan, and he abandoned his factory and sold his patents to Edison−Swan.



CHEMICAL LABORATORY.

Figure 5. Crookes’s chemistry laboratory at his home in Notting Hill in the 1880s. Note the fireplace has been made into a fume cupboard, and a place reserved for laboratory notebooks to its right. (From Brock, ref. (1), p. xxv.)

That was not the end of Crookes as an electrician since he went on to create a company to light the Notting Hill district of London where he lived and he remained a Director until his death. His electrical talents were also recognized by the Institute of Electrical Engineers (since 2006, the Institution of Engineering and Technology) which elected him as its President in 1891. His presidential address was a spectacular demonstration of the properties of cathode rays just six years before J. J. Thomson demonstrated the existence of the electron.

The Business Man

Crookes's involvement in the new age of electric lighting reminds us that throughout his life Crookes was a business man. Since he was not an academic teacher, income from non-teaching sources was essential. As we have seen, his ownership of *Chemical News* underlined the link between science and commerce that was the hallmark of his life. A cheeky aspect of this was his adoption of a Latin tag, "ubi crux, ibi lux", on his business stationery in the 1880s (Figure 6). He turned his experimental skills into marketable values in developing schemes for the disposal of town sewage and the reclamation of silver and gold from spent mining operations. His publishing links also gained him directorships of publishing companies. However, while Crookes was undoubtedly (and of necessity) commercially-minded, he had a relatively poor eye for any systematic development of his inventions and innovations. At the end of the day, this came down to a lack of capital and an inability to find suitable capitalist partners in his enterprises.

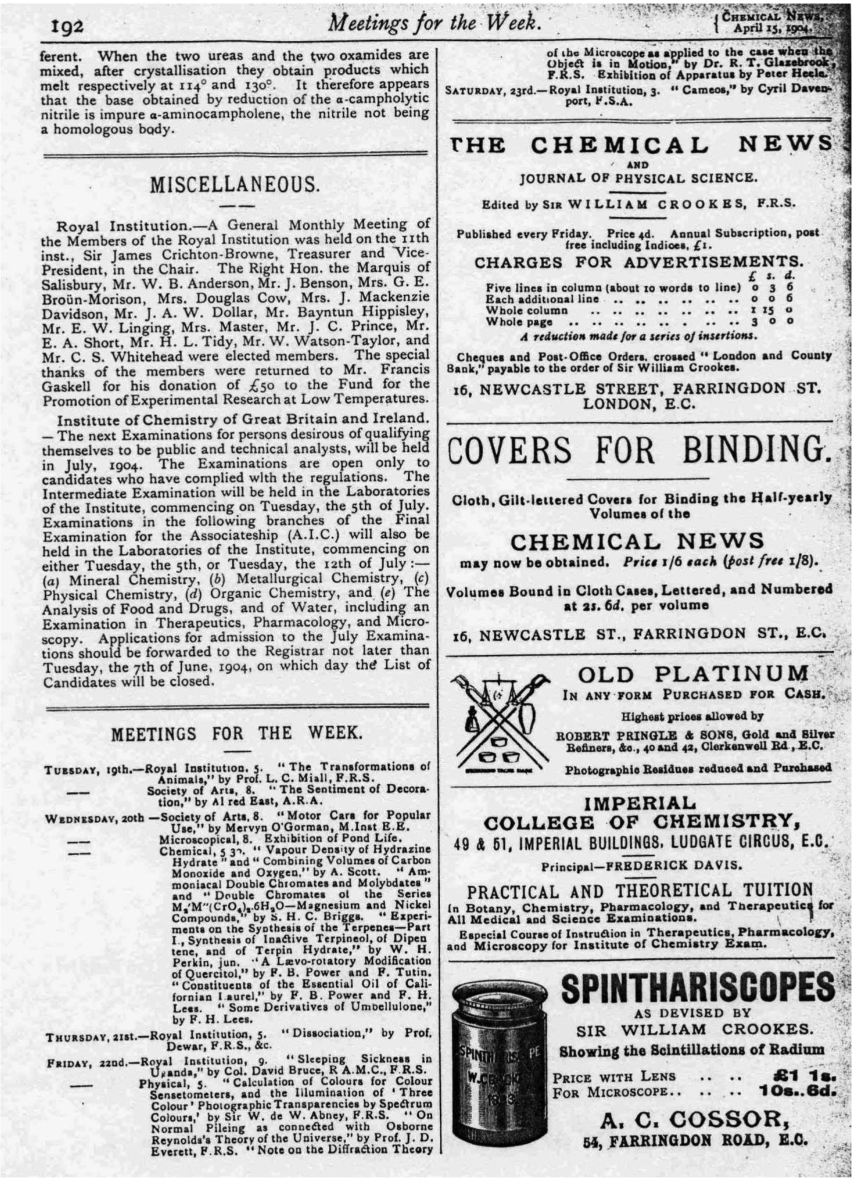
The Sage

In extending his work on the radiometer with the aid of his brilliant assistant Charles Gimingham, Crookes showed how what he called radiant matter in the evacuated space could be marshalled into straight lines. On hitting the glass boundary, or a sample of a rare earth element, phosphorescence occurred. This led Crookes to a new form of spectroscopy that seemed to indicate, or at least promise, the discovery of new elements, and even more excitingly, the conclusion that the known "elements" were compounded. The apparent fractionation of phosphorescent spectra led him to an evolutionary model of the elements and an explanation of the non-integral value of atomic weights (*12*). All of this work was presented in a series of brilliant lecture demonstrations to the Royal Institution, the Royal Society, the Chemical Society, and the Institute of Electrical Engineers that gave him international fame.

Figure 6. Crookes's bookplate after his knighthood in 1897. The elephant ("Nellie") symbolized the support his adored wife, Ellen, had given him during his career. (From copy in private possession.)

This fame marked him as the British expert on spectroscopy. Consequently, Crookes became a source of advice to Rayleigh and Ramsay when, in the absence of chemical tests, they had to use physical tests such as spectroscopy, to identify the noble gases at the end of the century. By then, Crookes was investigating radioactivity and inventing the instrument he called the spinthariscope (Figure 7), without which Rutherford would not have been able to identify and count alpha particles (*13*). Given the dexterity of Crookes's investigations with the Crookes tube, it is somewhat surprising that he did not discover X-rays before Rőntgen did at the end of 1895. He was away in South Africa acting as a witness in a patent trial when Rőntgen's announcement was made. However, Crookes quickly made up for lost time and was able to give the first demonstrations of X-rays in Johannesburg in February 1896. It is amusing to note that Crookes's assistant, James Gardener, was one of the founders of the Röntgen Society, which Crookes also joined. When the Society felt under pressure to change its Germanic name during the First World War, it was initially suggested that it should become the Crookes Society (in honour of the Crookes tube developed by Röntgen)! Since this would have led to ribaldry the society kept its name until 1927, when it became the staidly-named British Institute of Radiology. He was to visit South Africa again in 1905 under the auspices of the British Association for the Advancement of Science (BAAS) and on both occasions he took the opportunity to interest himself in diamonds and their mining. He published a fascinating book on diamonds in 1909 which he developed from a lecture that he had given to the

BAAS in Kimberley in 1905 (*14*). Crookes had regularly attended the annual meetings of BAAS since lecturing on thallium at the Newcastle meeting in 1863. In 1898 he was elected the Association's president and used the occasion to utter a warning that, unless chemists solved the problem of fixing the abundant supplies of atmospheric nitrogen in fertilizers, within the space of a mere forty years, the world would suffer mass starvation because of dwindling wheat supplies.



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ferent. When the two ureas and the two oxamides are mixed, after crystallisation they obtain products which melt respectively at 114° and 130°. It therefore appears that the base obtained by reduction of the α-campholytic nitrile is impure α-aminocampholene, the nitrile not being a homologous body.

MISCELLANEOUS.

Royal Institution.—A General Monthly Meeting of the Members of the Royal Institution was held on the 11th inst., Sir James Crichton-Browne, Treasurer and Vice-President, in the Chair. The Right Hon. the Marquis of Salisbury, Mr. W. B. Anderson, Mr. J. Benson, Mrs. G. E. Broün-Morison, Mrs. Douglas Cow, Mrs. J. Mackenzie Davidson, Mr. J. A. W. Dollar, Mr. Bayntun Hippisley, Mr. E. W. Linging, Mrs. Master, Mr. J. C. Prince, Mr. E. A. Short, Mr. H. L. Tidy, Mr. W. Watson-Taylor, and Mr. C. S. Whitehead were elected members. The special thanks of the members were returned to Mr. Francis Gaskell for his donation of £50 to the Fund for the Promotion of Experimental Research at Low Temperatures.

Institute of Chemistry of Great Britain and Ireland. — The next Examinations for persons desirous of qualifying themselves to be public and technical analysts, will be held in July, 1904. The Examinations are open only to candidates who have complied wlth the regulations. The Intermediate Examination will be held in the Laboratories of the Institute, commencing on Tuesday, the 5th of July. Examinations in the following branches of the Final Examination for the Associateship (A.I.C.) will also be held in the Laboratories of the Institute, commencing on either Tuesday, the 5th, or Tuesday, the 12th of July:—(*a*) Mineral Chemistry, (*b*) Metallurgical Chemistry, (*c*) Physical Chemistry, (*d*) Organic Chemistry, and (*e*) The Analysis of Food and Drugs, and of Water, including an Examination in Therapeutics, Pharmacology, and Microscopy. Applications for admission to the July Examinations should be forwarded to the Registrar not later than Tuesday, the 7th of June, 1904, on which day the List of Candidates will be closed.

MEETINGS FOR THE WEEK.

TUESDAY, 19th.—Royal Institution, 5. "The Transformations of Animals," by Prof. L. C. Miall, F.R.S.
— Society of Arts, 8. "The Sentiment of Decoration," by Alfred East, A.R.A.

WEDNESDAY, 20th—Society of Arts, 8. "Motor Cars for Popular Use," by Mervyn O'Gorman, M.Inst E.E.
— Microscopical, 8. Exhibition of Pond Life.
— Chemical, 5 30. "Vapour Density of Hydrazine Hydrate" and "Combining Volumes of Carbon Monoxide and Oxygen," by A. Scott. "Ammoniacal Double Chromates and Molybdates" and "Double Chromates of the Series $M_2'M''(CrO_4)_2.6H_2O$—Magnesium and Nickel Compounds," by S. H. C. Briggs. "Experiments on the Synthesis of the Terpenes—Part I., Synthesis of Inactive Terpineol, of Dipentene, and of Terpin Hydrate," by W. H. Perkin, jun. "A Lævo-rotatory Modification of Quercitol," by F. B. Power and F. Tutin. "Constituents of the Essential Oil of Californian Laurel," by F. B. Power and F. H. Lees. "Some Derivatives of Umbellulone," by F. H. Lees.

THURSDAY, 21st.—Royal Institution, 5. "Dissociation," by Prof. Dewar, F.R.S., &c.

FRIDAY, 22nd.—Royal Institution, 9. "Sleeping Sickness in Uganda," by Col. David Bruce, R.A.M.C., F.R.S.
— Physical, 5. "Calculation of Colours for Colour Sensetometers, and the Illumination of 'Three Colour' Photographic Transparencies by Spectrum Colours,' by Sir W. de W. Abney, F.R.S. "On Normal Pileing as connected with Osborne Reynolds's Theory of the Universe," by Prof. J. D. Everett, F.R.S. "Note on the Diffraction Theory of the Microscope as applied to the case when the Object is in Motion," by Dr. R. T. Glazebrook, F.R.S. Exhibition of Apparatus by Peter Heele.

SATURDAY, 23rd.—Royal Institution, 3. "Cameos," by Cyril Davenport, F.S.A.

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54, FARRINGDON ROAD, E.C.

Figure 7. Page from Crookes's Chemical News advertising the spinthariscope in 1904. From Chem. News. ***1904****. 89, 192.)*

This shocking prediction marked out Crookes as a sage. Students of Victorian studies are familiar with the way that writers like Coleridge, Carlyle, Arnold, Ruskin and others raised prophetic voices concerning the fate of contemporary social and cultural assumptions (*15*). Crookes, too, had a fine ear for capturing the ideas of his contemporaries and for moulding heterodox views into evocative and plausible hypotheses. Although already discernible in his popular writings, the sageness came to the foreground in his speculations concerning the fourth state of matter and his views on the evolution of the elements from a fundamental protyle. The address on the wheat problem in 1898, with its wake-up call, to chemists, came only a few months after his presidential address to the Society for Psychical Research in which he had speculated on telepathy, as well as on the possibility of wireless transmission. A few years later, when he became one of the principal workers on radioactivity, he again speculated about the future uses of radium. Given his fame and image as Britain's elder statesman of science it is not surprising that he was awarded the exclusive Order of Merit in 1910 and that he was chosen to succeed the geologist Sir Archibald Geikie as President of the Royal Society in 1913.

The Grand Old Man of Chemical Physics

Each of the afore-mentioned aptitudes can be brought together in a single characteristic feature of Crookes, namely an obsession with Prout's hypothesis and the possibility of transmutation. In an essay published in 1912, Frederick Soddy recalled how Michael Faraday had once said that "transmutation is the final goal towards which chemistry should aspire". Soddy then added:

> The power to decompose and build up the known elements and to construct new ones at will as is now done for compounds, would elevate chemistry to an infinitely loftier plane than the rather secondary and subordinate position among the physical sciences it occupies at the moment (*16*).

According to the physicist Norman Feather, Soddy's comment echoed a letter that Faraday sent to Crookes in 1861 congratulating him on the discovery of thallium.

> To discover a new element is a very fine thing, but if you could decompose an element and tell us what it is made of – that would be a discovery indeed worth making (*17*).

Just as in the seventeenth century the new corpuscular philosophy appeared to support alchymical speculations concerning the possibility of the transmutation of base metals into gold (and visa versa), nineteenth-century chemists and physicists built up an impressive cluster of arguments for possibility of transmutation between elements. Chief among these was Prout's hypothesis of 1816 that, since the relative atomic weights of Dalton's chemical atoms were whole numbers, it was possible that the so-called elements were really compounds of hydrogen, the simplest of the elements. As is well known, the hypothesis was taken up enthusiastically, but uncritically, by Thomas Thomson; and heavily criticized by Jacob Berzelius. That was not the end of the matter because, while Edward Turner and others agreed that Berzelius's analytical work was more accurate than Thomson's, the close proximity of atomic weight values to decimals ending in halves or quarters, opened the door to further speculation that elements might still be polymers of an unknown material that was lighter than hydrogen (*18*). Because the accurate determination of atomic weights remained one of the chief interests of nineteenth-century chemists, Crookes must have come across the speculation as a young man. Indeed, in a later criticism of the way examinations were killing the practical skills that were most needed in a professional chemist, he erroneously assumed that the musician, Ebenezer Prout, was a son of William Prout, and that he had been awarded a prize for chemistry in university examinations without ever holding a test tube in his life (*19*). By then Crookes was well aware that the Belgian analytical chemist Jean Servais Stas had demonstrated in meticulous work lasting several years that Prout's hypothesis was simply not true.

Crookes revered Stas as the most accurate analyst of his generation and after Stas's death in 1891 he subscribed to the erection of a public statue and to the publication of Stas's collected papers. Despite Stas's condemnation of Prout's hypothesis in its simplest form that was not, of course, the end of the matter. Crookes and other chemists continued to speculate that the familial similarities among the chemical properties of the elements (finally codified in Mendeleev's periodic law in 1869), the fact that many elements presented themselves in allotropic forms, the fact that isomerism was rife among carbon compounds and that organic radicals behaved to all intents and purposes as if they were "elementary" bodies, all suggested that elements were compound bodies. Crookes gave plenty of houseroom to such speculations in *Chemical News*, especially in the 1870s when the activities of Norman Lockyer (editor of the weekly *Nature* that Lockyer modelled on *Chemical News*) suggested that there were common lines in the spectra of elements. Indeed, Lockyer's suggestion that the solar spectrum represented the dissociation of elements was directly linked by him to the idea of an evolution of the so-called earthly elements as the earth cooled down –an idea that Crookes took up enthusiastically in his interpretation of his own work on cathode rays and in his investigations of the spectra of the rare earth metals (lanthanides) in the 1880s.

As an illustration of this obsession with Prout's hypothesis, consider the publicity that Crookes gave to the otherwise extremely obscure and bewildering work of Sir Benjamin Collins Brodie, the professor of chemistry at the University of Oxford. "The chemistry of the future" was a phrase first coined by Crookes in 1867 when reporting on Brodie's chemical calculus of operations. Was Brodie's anti-atomic calculus the future? The general opinion of chemists, including Crookes, was that while the mathematical system that Brodie wanted to substitute for Dalton's atomic theory, was not the future; what struck most chemists was the calculus's implicit implication that elements were compounds, thus reviving Prout's speculation that elements were polymers of hydrogen – a speculation that everyone thought Stas's work on the redetermination of atomic weights in the early 1860s had scotched once and for all.

Ten years later in 1877 Crookes used the phrase again in his *Quarterly Journal of Science.* This time the context was the observation of gaps in the periodic table and the possibility that the known list of elements actually represented a past Darwinian struggle for existence. What chemists extracted and defined as elements, Crookes suggested, were complex compounds that had evolved from a basic matter (he called it *protyle*, as Prout had done) that had condensed on cooling to form them. The future of chemistry lay in the deeper investigation of these manufactured particles and meta-elements using the tool of spectroscopy and electrical discharge phenomena to capture the basic matter. As we have already stated, it was this programme that led Crookes to cathode rays and the fourth state of matter, or radiant matter, that J. J. Thomson later identified as the electron. Another development was to illustrate the genesis of the elements by the construction of a three-dimensional model of the periodic system (Figure 8).

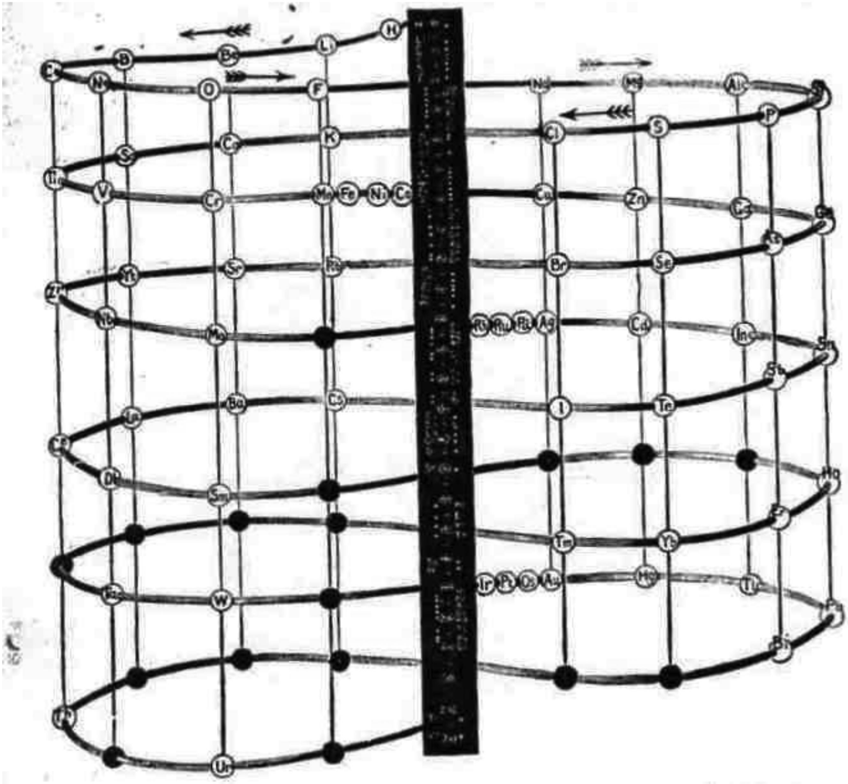

Figure 8. Crookes's three-dimensional spiral periodic table illustrating the genesis and evolution of the elements. (From Chem. News. ***1898****. 78, 25.)*

It is not surprising, therefore, that Crookes was only too happy to report in *Chemical News,* stories that appeared to support the possibility of transmutations. The most extraordinary of these was that of the sensational Emmens argentaurum process. Crookes's attention had been drawn to Emmens by the American chemist and bibliographer, H. Carrington Bolton, who was a regular correspondent in *Chemical News*. The latter had publicised the news of an alchemical revival in Europe in 1897 and noted the way that Crookes's work had been seized on by occultists and by Stephen Emmens of New York. Emmens, an Irish−American consultant chemist, claimed to have converted Mexican silver dollars into *argentaurum*, a form of gold, using very cold temperatures and high pressure (*20*). The presence of gold in the samples of argentaurum was confirmed by US Government Assay Office. Emmens himself hinted that the process involved the application of Thomas Andrews's notion of critical temperature to solids and he claimed to have built a force engine capable of exerting 500 tons per square inch.

Bolton thought Emmens a crackpot and fraud who was using some of the same tricks as the early-modern alchemists had done. But, Crookes, who was always on the lookout for anomalous phenomena, and who was convinced that there was a grain of truth in Prout's hypothesis, was prepared to give Emmens the benefit of the doubt. Accordingly, Crookes asked for samples and struck up a correspondence with him. Given Crookes's international fame, Emmens was only too happy to oblige. Sure enough, the spectrum of a sample of argentaurum did reveal the presence of silver and gold, as well as some copper. Crookes, while not denying the possibility of transmutation, thought a direct transmutation between silver and gold unlikely. He offered visit New York to inspect Emmens's apparatus, but was craftily put off by Emmens who said it would be pointless because no one would believe Crookes even if he verified Emmens's claims. Accordingly, Crookes made his own tests on Mexican dollars with a piston machine he devised. He placed coin shavings under pressure for 40 hours at a time, but analysis only showed the same amounts of gold in treated and untreated coins. He also found that in pure samples of the dollars that lacked gold, no gold was detected after pressure. At this point Crookes exploded into anger when Emmens printed their private correspondence without permission and terminated any further discussion. He had realized that he was being taken for a ride.

Crookes was also tangentially involved in another curious episode. As we have seen, Crookes got involved in psychic research in the 1870s. He also became an active member of the Society for Psychical Research following its foundation in 1882. Less well known is the fact that he joined Madame Blavatsky's Theosophical Society in 1883, probably because he genuinely admired its universalist concept that there was a kernel of truth in all the world's religions and that much could be learned from Eastern religions. In 1895 Annie Besant (who had studied some chemistry at London University), inspired by Crookes's work on radiant matter as the primary matter of the elements, developed a clairvoyant chemistry in which she and her partner Charles Leadbeater imagined themselves as Lilliputians peering into the interior of atoms and mapping their structures. An elaborate version of this "occult chemistry" was published as a book in 1908. Was this the chemistry of the future? Crookes kept quiet and said nothing, though earlier in 1895 he had politely stated that Besant's models might offer clues on where to look for missing elements. "Occult Chemistry" now looks very odd and suspicious and even a fraudulent pretence, but at the time it was no odder than what was happening in radioactivity and in the laboratory of William Ramsay at University College London.

Ramsay is best known for his collaboration with Lord Rayleigh in the discovery of argon in 1894, and his independent research in identifying the other rare or inert gases, including radon. His investigations with the latter radioactive gas led him into murky waters that are less well known today, but which had an interesting postscript. In 1903 he and Soddy put radon in a spectrum tube and after a few days detected the presence of helium that had not been there previously. Needless to say, it was Crookes who was asked to validate this amazing conclusion. On the one hand this confirmed the disintegration theory that Rutherford and Soddy had previously hinted at; on the other hand, it led Ramsay into speculative experiments whether it might be possible to reverse radioactivity dissociation (as he saw it) and to use its energy to synthesize elements. Beginning in 1907 Ramsay tried to transmute elements using radon as an energy source. He claimed that when pure water that had been exposed to radon was electrolyzed, an excess of hydrogen was produced. And when the same was done with a copper salt he believed he detected lithium (*21*). Although Rutherford rubbished these claims, Ramsay persisted with the experiments and announced the transmutation of copper into lithium in a lecture to the London Institution in January 1907. Similar claims were made by him from then until 1912 when he announced that neon came from water and that he had synthesized argon from hydrogen and sulfur. His *Elements and Electrons*, also published in 1912, stood by such claims and also, intriguingly, speculated that the alpha particle would eventually turn out to be an energy bullet or Philosophers' Stone for the promotion of transmutation (in which he was proved right by Rutherford in 1919).

Although viewed sceptically by the majority of chemists and physicists (especially by Rutherford and Bertram Boltwood who had scathing things to say in their private correspondence about Ramsay's procedures and use of contaminated stopcock grease), these announcements had a popular impact. Was transmutation possible? Had the old alchemists been right? What had the alchemists been trying to do? To answer these questions was the purpose of a short-lived Alchemical Society founded in 1912 (*22*).

So, by the beginning of the First World War it really did seem as if transmutation was the future of chemistry and "the final goal towards which chemistry should aspire". Crookes confided to a friend: "a few decigrammes of radium have undermined the atomic theory of chemistry, revolutionised the foundations of physics, revived the ideas of the alchemists, and given some chemists [i.e. Crookes himself] a bad attack of "swelled head" (*23*). Crookes, however, died in April 1919 and therefore did not live to witness Rutherford's demonstration in June of same year that atoms contained protons, or Aston's announcement that isotopes are integral multiples of H=1 or $^{1}/_{16}$ of mass of oxygen. Whether this enhanced chemistry's position with respect to physics as Soddy thought, the effect of the possibility elemental transmutation was seemingly to reduce chemistry to physics and thereby demean its power. This remains a perennial contention among philosophers of chemistry.

Crookes, as a solo worker lacking the facilities of a large academic laboratory, could not compete with Rutherford in the advancement of understanding of radioactivity (Figure 9). In 1905, at the age of 75, he accordingly abandoned this exciting field of research and returned to work on the spectra of the rare earth elements, the investigation of diamonds and, in his brilliant swansong, the manufacture of glass (*24*).

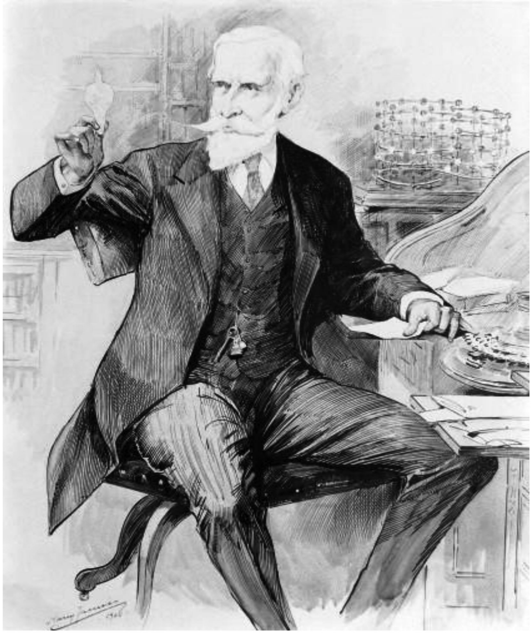

Figure 9. Crookes holding a radium sample; sketched by Harry Furniss in 1906. Note the typewriter and the spiral periodic table. (Reproduced by permission of Welcome Library, London.)

Conclusion

There were certainly negative features to Crookes's character. Although a sociable man, he was little interested in literature or the arts. We cannot overlook the debts he owed to his hard-working assistants, Charles Gimingham from 1870 to 1880 and James Gardener from 1880 to 1919, as well as to the more theoretical help he had continually from the physicist George Stokes, and the constant assistance and support from his wife and children in his home laboratory (*25*). On several occasions he displayed anger at his competitors and an unwillingness to share credit for a particular achievement. In business he drove many hard bargains and made moral compromises.

Crookes's career was that of an independent chemical innovator, initially in photography and then in spectroscopy. Spiritualism tarnished his reputation for a time, but he quickly burnished it with his brilliant investigations of cathode rays, the fourth state of matter, rare earth spectroscopy and radioactivity. He ended up a celebrity (Figure 10). Scientists who, like Crookes, take all of the sciences for their province, frequently face censorious criticism in their life-times. The most controversial aspect of Crookes's career, even today, is his investigation "into the phenomena called spiritual" during the 1870s. After Darwin, it fell to Crookes to provoke the last major eruption in the issue of the implications of science for religion. To the delight of many non-scientists here was an attack on Authority, which had been encouraging an increasingly materialistic view of the universe. If scientists would look, as Crookes had done, theory would find that there was more to the universe than atoms and energy, dissection and vivisection, microbes and antiseptics. The case of Crookes, or rather the character of Crookes, demonstrates how religion, metaphysics and individual personality play a creative role in scientific life. Today, Crookes's interest in psychic phenomena appears to many as silly and credulous. But to Crookes, confident that there were mysterious forces awaiting identification, such investigations were essential. The fact that mediums frequently perpetuated fraud did not disprove the existence of strange forces in nature. Had it not been for Crookes's curiosity over mediumship, it is doubtful whether the mis-behaviour of the balance during the extremely tedious thallium atomic weight determinations would have excited his desire for analogy and synthesis. Nor perhaps would it have transformed him from an analytical chemist into someone who can be fairly described as the first of the nuclear physicists.

Figure 10. Crookes with a group of Fellows of the Royal Society in 1885. In the front row are Stokes, Hooker, Huxley, Tyndall, Owen and Crookes. The chemist Williamson stands immediately behind Crookes. (Reproduced by permission of Wellcome Library, London.)

Although Crookes was never able to visit the United States of America, he was made an Honorary Member of the Chemists' Club in New York in November 1909 in commemoration of the publication of the hundredth volume of *Chemical News*. On that occasion, Charles Baskerville, the professor of chemistry at the City of New York College, who had separated two spurious elements (carolinium and berzelium) from thorium, wrote (*26*):

> Punctilious in the performance of every duty, courteous but vigorous in argument, modestly assertive, learning from the youngest, Sir William draws out the humblest until he would become almost bold, yet, in return, he gives generously from his rich store of wide knowledge and large experience. Such is the man the trustees would have the club honor and thus gain luster itself, for William Crookes, the *savant*, ornaments any company, and his life work is an inspiration for the present generation and the generations of men of science to come.

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Chapter 7

It's a Gas! Sir Humphry Davy and His Pneumatic Investigations

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Always a popular figure in the history of chemistry, the life and accomplishments of Sir Humphry Davy are hard to ignore. Often styled a self-made chemist, he went on to achieve far more than most of the conventionally trained scientists of his time, including the isolation and identification of several new chemical elements. However, what has always made him a true '*Character in Chemistry*' in my view was his early work with nitrous oxide and an unflinching willingness to make his own body a central aspect of experiments. In hindsight, it seems that his ability to survive his early pneumatic studies was more luck than insight, but early successes from these risky studies provided him the fame and recognition to build a career that would follow with even greater discoveries. The life and work of Davy will be presented, focusing on his early work with gases at Beddoes' Pneumatic Institution.

Introduction

It is easy for society to maintain the stereotypical view of science—the sterile, cold image of laboratory activities being carried out by highly educated, but passionless, white lab-coated minions. However, for those of us who have been (or still are) such minions, we know that this is far from reality. Science is very much a human endeavor and is carried out by a wide variety of 'characters', some of whom fit the stereotypical view of the scientist, but there are many, many more who definitely do not. Perhaps the most effective way of conveying a

In Characters in Chemistry: A Celebration of the Humanity of Chemistry; Patterson, G., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

more realistic picture of the nature of science is by sharing a more complete and unsanitized view of its history. This approach includes not just the discoveries themselves, but also those involved, as well as the culture and environment that shaped their actions (*1*). Such a complete picture allows society to witness the reality of science at work, including all the error, approximation, and human failings (*1*, *2*). In the process, one can see that while intellect and education are important factors in the path to great discoveries, so too are enthusiasm, optimism, intuition, and an appetite for hard work (*1–3*). Of course, a bit of luck never hurts either.

When invited to join this current project on '*Characters in Chemistry*', a single name came forth for the 'character' that I would most wish to highlight. That of course was Sir Humphry Davy (1778–1829), shown in his later years in Figure 1. Son of a Cornish woodcarver, Davy rose to become a leader in the new chemistry movement following Lavoisier's chemical revolution of the 18th century. Not only was Davy a pioneer in the new field of electrochemistry, but he used the newly developed method of electrolysis to discover a number of new chemical elements (*4–6*). These included potassium and sodium, as well as magnesium, calcium, strontium, and barium, which represented the first known examples of metallic alkali and alkaline earth elements. Later, he went on to also demonstrate the elemental nature of two previously known species—chlorine and iodine (*4*, *5*).

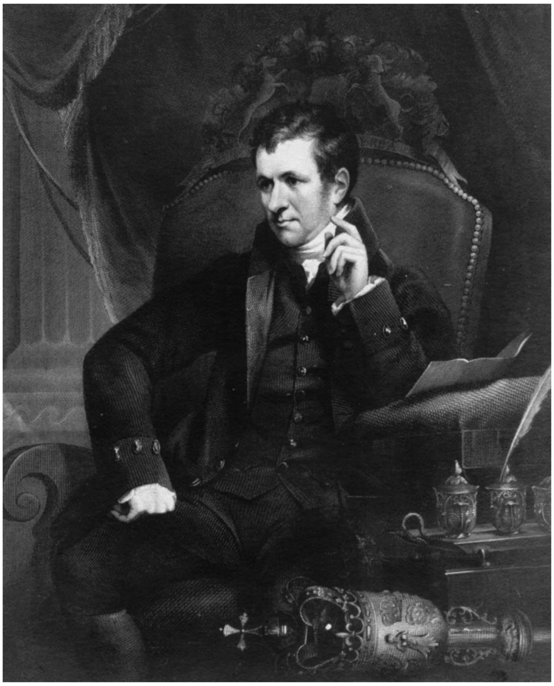


Figure 1. Sir Humphry Davy (1778–1829). (Edgar Fahs Smith Collection,University of Pennsylvania Libraries).

While his greatest discoveries occurred later in his career, it is his early work with nitrous oxide and other gases that will be the focus here, as it is this period that shows the more colorful aspects of his life while also best illustrating some of the realities of scientific pursuit. In many respects Davy was a self-taught chemist, and when faced with the assigned study of newly discovered families of gases, he brazenly entered the pursuit of their biological effects while making himself a central aspect of experiments. In hindsight, it seems that his ability to survive these early pneumatic studies was more luck than insight. However, if it wasn't for the early successes from these risky studies, he might not have been able to accrue the fame and recognition that opened doors to later opportunities, thus allowing him to go on to the greater discoveries for which he is more well-known.

Early Years

Davy was born Saturday, December 17, 1778 in the town of Penzance (*4–10*), located on the western tip of Cornwall, the southwesternmost county of England (Figure 2). His father Robert was a woodcarver descended from generations of educated yeoman (*5*, *8–10*), while his mother Grace Millet was the ward of Mr. John Tonkin (ca. 1719−1801), a surgeon and apothecary (*11*) of Penzance (*4*, *6–8*). Tonkin assumed responsibility for the Millet children following the sudden and unexpected death of their natural parents when Grace was only eight. Madron Parish records show that Humphry was christened on January 22, 1779, named after Grace's deceased father, Humphry Millet (*7*). Humphry was the first of five eventual siblings—Humphry, Katherine (commonly called Kitty), Grace, Elizabeth (commonly called Betsy), and John (*5*, *7*, *8*).

During Davy's infant years, his family lived in a house located on Market Jew Street, Penzance (*7–9*). In 1782, however, his father began building a house on a 79-acre farm owned by the family in Varfell (*7*, *9*), about two-and-a-half miles northeast from Penzance. When Humphry turned five, he was sent to a local preparatory school, but stayed only a short time before being enrolled at the local Grammar School in Penzance, under the care of the Rev. J. C. Coryton (*7*, *8*, *10*). During this change in schools, Davy's father had finished the house in Varfell, which meant the family could move out to the farm. As travel between the farm and Penzance for school was too far for one so young, Davy moved in with his mother's guardian John Tonkin, on August 29, 1784 (*7*). Tonkin, however, saw to it that Davy was not totally isolated from his family and they made weekly visits to the farm on Saturdays. In addition, Davy would stay with his family at the farm during holidays (*8*). During his time living in the Tonkin residence, Tonkin provided for the majority of Humphry's needs, while the family sent him fruit, vegetables, and other produce from the farm in return (*7*).

By 14, Davy had completed the local curriculum and transferred as a boarder to the Truro Grammar School in 1793, with his tuition, room, and board all paid by Tonkin (*7*, *8*, *10*). The only major city in Cornwall, Truro is located approximately 24 miles northeast of Penzance (Figure 2), and must have been a bit of an adjustment for Davy. At Truro, it has been reported that the headmaster, Rev. Cornelius Cardew (1747−1831), had found Davy ill-prepared and behind the other boys of his age. However, he assured Davy that if he worked hard, he would be allowed to stay with his classmates and not held back. To Cardew's satisfaction, Davy was able to catch up successfully, although Cardew never viewed Davy as a student of extraordinary abilities (*7–9*). Other than some training in Latin and Greek (*7*) and a bit of elementary mathematics (*9*), it is unclear precisely what Davy learned during his year at Truro. Shortly after his 15th birthday, on December 22, 1793, Davy returned to Penzance to stay again with Mr. Tonkin (*7*) and it has been stated that the majority of his early general knowledge was self-taught from books found in Tonkin's library (*9*).

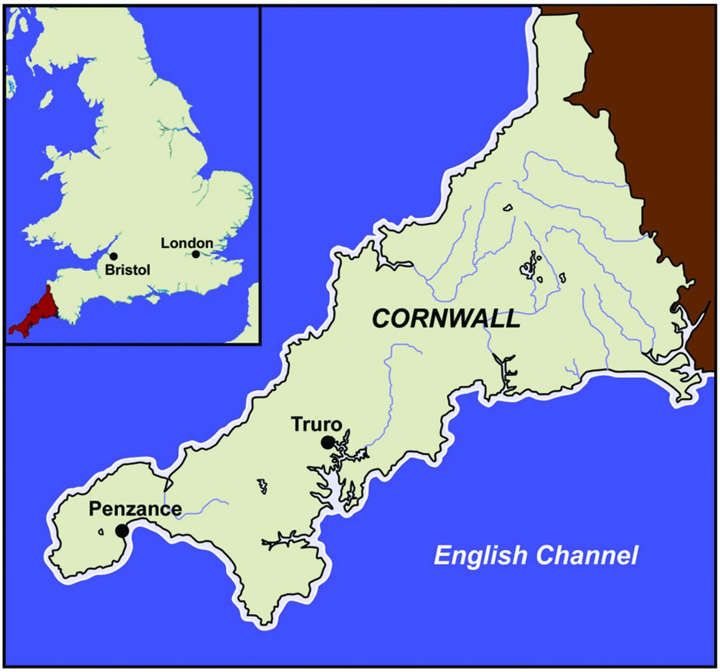


Figure 2. Map of Cornwall, England.

In December of 1794, shortly before his 16th birthday, Davy's life changed significantly when his father Robert died at the relatively young age of 48 (*5*, *7–10*). Robert has been described as a man of some ability, but who had been too fond of recreation and fishing to have made proper provision for his family after his death (*4*). It is said that he had practiced his art of wood-carving irregularly (*9*), possibly due to lack of demand for carvings in the area (*7*). His efforts in farming at Varfell were largely unsuccessful (*9*, *10*) and while improvements to the land had been accomplished, the resulting expense of those efforts was even greater (*7*). In addition, Robert's hopeful investments in failed Cornish mines proved costly for the family (*7*, *10*) and at his death, the family was in difficult financial circumstances (*9*). As a result, Davy's mother Grace rented out the farm at Varfell and moved her family back to Penzance (*7*). To make ends meet, Grace partnered with a French woman to open a millinery shop (*8–10*), but the family's reduced income did not allow a leisurely existence (*5*).

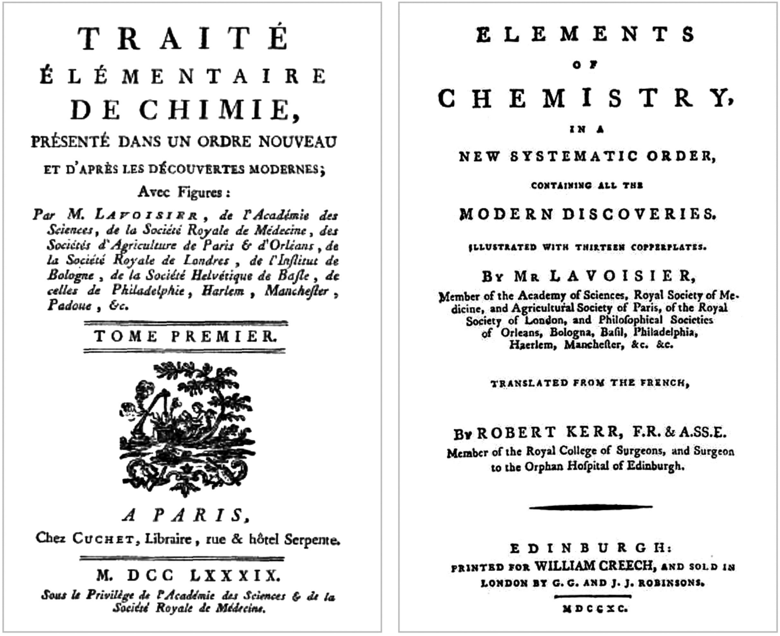
Apprenticeship and Chemical Beginnings

At the advice of Mr. Tonkin, Grace apprenticed Humphry to Mr. John Bingham Borlase, a fellow surgeon and apothecary practicing in Penzance (*4*, *5*, *10*, *12–14*). Tonkin paid the indenture fee for this apprenticeship as he saw Davy as the logical heir of his medical practice and Humphry's new life as an apprentice thus began February 10, 1795 (*10*, *12*, *13*), at the age of 16. Borlase was to teach Davy the profession of surgeon, as well as that of apothecary (*11*), which would allow him to become a general practitioner in his native town (*13*). Davy, however, hoped to eventually attend the University of Edinburgh in order to become a physician (*10*, *12*, *13*).

Before he signed the formal apprenticeship agreement, Davy outlined for himself an ambitious course of study as part of his training. This plan included theology, geography, logic, languages, mathematics, and a range of sciences from botany to physics (*5*, *12*, *14*). It is not known whether Tonkin or Borlase assisted in developing this plan of study, or if Davy conceived of it completely on his own. While his early studies seemed to concentrate on theology and metaphysics, he also learned French from M. Dugart, an émigré priest with whom he worked twice a week (*7*, *10*, *13*). It has been said that while he acquired fluency of the written language, his spoken French was handicapped by a strong accent.

Davy turned to the study of mathematics in the early part of 1796 (*12*, *14*). In addition to the academic parts of his plan, Davy also aspired to be a poet and wrote a number of poems during 1795 and 1796, of which at least five were later published (*12*). The following year he began the study of natural philosophy and shortly after his 19th birthday in 1797, Davy's attention turned to chemistry (*4*, *10*, *12*, *14*). Davy began his study of the subject with William Nicholson's *Dictionary of Chemistry*, published in 1795 and Antoine Lavoisier's *Traité élémentaire de chimie* (*Elements of Chemistry*), originally published in 1789 (Figure 3) (*4–6*, *10*, *12*, *14*). There is some disagreement as to which version of Lavoisier's text was studied by Davy, the original French text (*10*, *15*, *16*) or the English translation by Robert Kerr, published in 1790 (*4*, *14*). As Davy could read French by this point, his reading the original text is certainly reasonable, although the argument could also be made that the English edition might have been more readily available in the small town of Penzance.

These texts formed the foundation of Davy's chemical knowledge and exposed Davy to the kinds of experimental questions worth investigating. In addition, the appendix of Nicholson's text provided him with precise descriptions of the sort of apparatus he would need for proper investigations, including diagrams for constructing the necessary equipment and good directions for manipulating such apparatus (*12*). As a result, Davy began collecting available pieces and attempting his first chemical experiments by March of 1798 (*6*). His apparatus, however, were primitive and either scavenged or manufactured out of the various materials he could find (*13*). Thus, phials, wine-glasses, teacups, and some pots and pans from the kitchen became his main tools, although sometimes augmented by the occasional earthen crucible or instruments borrowed from Tonkin's surgery (*13*, *14*). Likewise, his basic stock of chemicals was limited to the common mineral acids and alkalis, along with a few drugs scavenged from the surgery (*14*). Despite such limitations, he was soon experimenting in Tonkin's attic, which had now become the scene of his chemical operations (*13*). Even so removed, however, his chemical manipulations were not always so isolated from the rest of the house and Tonkin has been reported to have exclaimed "*This boy Humphry is incorrigible!*" and "*He will blow us all into the air!*" in response to the alarming noises which were sometimes produced during Davy's experimentation (*13*, *14*).



TRAITÉ
ÉLÉMENTAIRE
DE CHIMIE,
PRÉSENTÉ DANS UN ORDRE NOUVEAU
ET D'APRÈS LES DÉCOUVERTES MODERNES;
Avec Figures:
Par M. LAVOISIER, *de l'Académie des Sciences, de la Société Royale de Médecine, des Sociétés d'Agriculture de Paris & d'Orléans, de la Société Royale de Londres, de l'Inſtitut de Bologne, de la Société Helvétique de Baſle, de celles de Philadelphie, Harlem, Mancheſter, Padoue, &c.*
TOME PREMIER.

A PARIS,
Chez CUCHET, Libraire, rue & hôtel Serpente.
M. DCC LXXXIX.
Sous le Privilège de l'Académie des Sciences & de la Société Royale de Médecine.

ELEMENTS
OF
CHEMISTRY,
IN A
NEW SYSTEMATIC ORDER,
CONTAINING ALL THE
MODERN DISCOVERIES.
ILLUSTRATED WITH THIRTEEN COPPERPLATES.
By Mr LAVOISIER,
Member of the Academy of Sciences, Royal Society of Medicine, and Agricultural Society of Paris, of the Royal Society of London, and Philoſophical Societies of Orleans, Bologna, Baſil, Philadelphia, Haerlem, Mancheſter, &c. &c.
TRANSLATED FROM THE FRENCH,
By ROBERT KERR, F.R. & A.SS.E.
Member of the Royal College of Surgeons, and Surgeon to the Orphan Hoſpital of Edinburgh.

EDINBURGH:
PRINTED FOR WILLIAM CREECH, AND SOLD IN LONDON BY G. G. AND J. J. ROBINSONS.
MDCCXC.

Figure 3. Title page of the first volume of Lavoiser's Traité élémentaire de chimie (1789) and Kerr's English translation (1790).

One of the first original experiments was an investigation of quality of the air contained in the bladders of seaweed (*13*). His most significant early work, however, were investigations into the nature of light and heat (*12*). It was this latter work that would then attract the attention of Dr. Thomas Beddoes (*4*).

Beddoes and the Pneumatic Institution

Thomas Beddoes (Figure 4) was born April 13th, 1760 at Shifnall, in Shropshire (*17–19*). At age 16, he entered Pembroke College, Oxford in the fall of 1776 (*18*, *20*). He completed his Bachelor of Arts degree there in 1781, after which he ceased to reside regularly at the University and began to devote himself to more strictly professional studies (*18*). That same year, he went to London to study anatomy and physiology with John Sheldon (1752−1808), followed by a summer in Shropshire, before returning to Oxford to receive a Master of Arts degree in 1783. He then moved to Edinburgh in the fall of 1784 to finish his medical education (*17–20*).

While at Edinburgh, he was exposed to the theories of John Brown (1736−1788), who postulated that diseases were either the result of under-excitation or over-excitation (sometimes described as over-irritability) (*17*, *21*, *22*). Brown's theories thus led to the conclusion that the cure of such diseases required the administration of the proper stimulant or depressant to restore the patient's natural balance (*21*). During his time at Edinburgh, Beddoes also attended the chemical lectures of Dr. Joseph Black (1728−1799) (*22*). It was from Black that Beddoes deepened his knowledge of the developing pneumatic chemistry and acquired insights into Black's ideas about latent and specific heats (*17*, *20*).

Figure 4. Dr. Thomas Beddoes (1760−1808). (From the frontpiece of Stock's 1811 Memoirs of the Life of Thomas Beddoes).

In 1786, Beddoes again returned to Oxford to take his medical degrees, receiving his M.D. on December 13th (*19*, *20*, *24*). After this, he assumed an uncertain and independent post at Oxford and began lecturing on various chemical and geological subjects as early as February 1787 (*17*, *20*, *23*, *24*). These efforts were not financially supported by the University and he was completely dependent on fees paid by the students who attended his lectures (*24*).

In the autumn of 1787, he traveled to France (*17*, *18*, *24*). There he visited the laboratories of Louis Bernard Guyton de Morveau (1737−1816) in Dijon and Antoine Lavoisier (1743−1794) in Paris, which exposed him to the changes in nomenclature and conceptualization of chemical reactions being introduced by the French studies (*19*). Beddoes viewed the relatively new gas oxygen to be an element necessary for life, and thought it provided an important connection between pneumatic chemistry and the theories of John Brown, in which oxygen served as a principle of irritability (*17*). This connection suggested the untapped potential of a union between chemistry and medicine, which became a passion of Beddoes.

Beddoes and his lectures at Oxford were said to be quite popular and he soon enjoyed a reputation of possessing distinguished talents (*18*). Beddoes' enthusiasm for chemistry, however, was short-lived. Decreasing student interest in the subject resulted in low attendance at his lectures and thus lower income for Beddoes (*22*). In addition, his endorsement of the French revolutionary ideals did not endear him to the conservative Oxford leadership and he left the University in 1793 (*17*, *18*, *20*, *22*, *23*).

After leaving Oxford, Beddoes wanted to test the efficacy of gaseous inhalations for curing tuberculosis and he went to London to discover if suitable premises and patients were available. The search was unsuccessful and Beddoes decided to settle near Bristol instead (*17*, *20*, *22*). There he began a medical practice and continued to work on his research of tuberculosis (*23*). Following Brown's theoretical framework, he believed that tuberculosis arose because patients breathed too much oxygen, thus resulting in over-irritability. He therefore proposed to see if he might be able to affect a cure by patients inhaling airs with a reduced oxygen content (*16*, *17*). He published his concepts for treating tuberculosis with gases in an open letter to Erasmus Darwin entitled "*On a New Method of Treating Pulmonary Consumption and Some Other Diseases Hitherto Found Incurable*" in 1793, which was later followed by a pamphlet entitled "*A Proposal towards the Improvement of Medicine*" in 1794 (*17*).

In order to put Beddoes' ideas into practice, he collaborated with James Watt (1736−1819), who devised for him an apparatus for the manufacture of various clinically acceptable gases, including oxygen, nitrogen, carbon dioxide, and hydrogen (*17*, *20*, *22*, *23*). This increased the number of possible gases for Beddoes to test and Watt continued to design equipment for containing and delivering them in measured amounts. These collaborative efforts of Beddoes and Watt were then published as a five-part serial publication entitled "*Considerations on the Medicinal Use of Factitious Airs*", with the final parts published in 1796 (*17*, *19*, *20*, *22*).

These efforts eventually culminated in Beddoes founding his Pneumatic Institution at Bristol in 1798. The initial funding of the Institution was provided by Beddoes' long-time friend William Reynolds, William's brother Joseph, and Beddoes' early mentor Mr. Yonge, a surgeon of Shifnall (*20*, *25*). The Institution as envisioned by the four men was to include a hospital for patients, a laboratory for research, and a theater for lecturing (*14*). The Institution was finally established in Dowry Square (Figure 5), within the district of Hotwells, just southwest of the more elegant Bristol suburb of Clifton (*4*, *25*, *26*). The finished facility consisted of two adjacent houses that had been altered to create a lecture room, space for 10 inpatients and additional outpatients, as well as a laboratory (*19*). It was here that the effects of various newly discovered gases on the human body were to be investigated under the guidance of Beddoes.

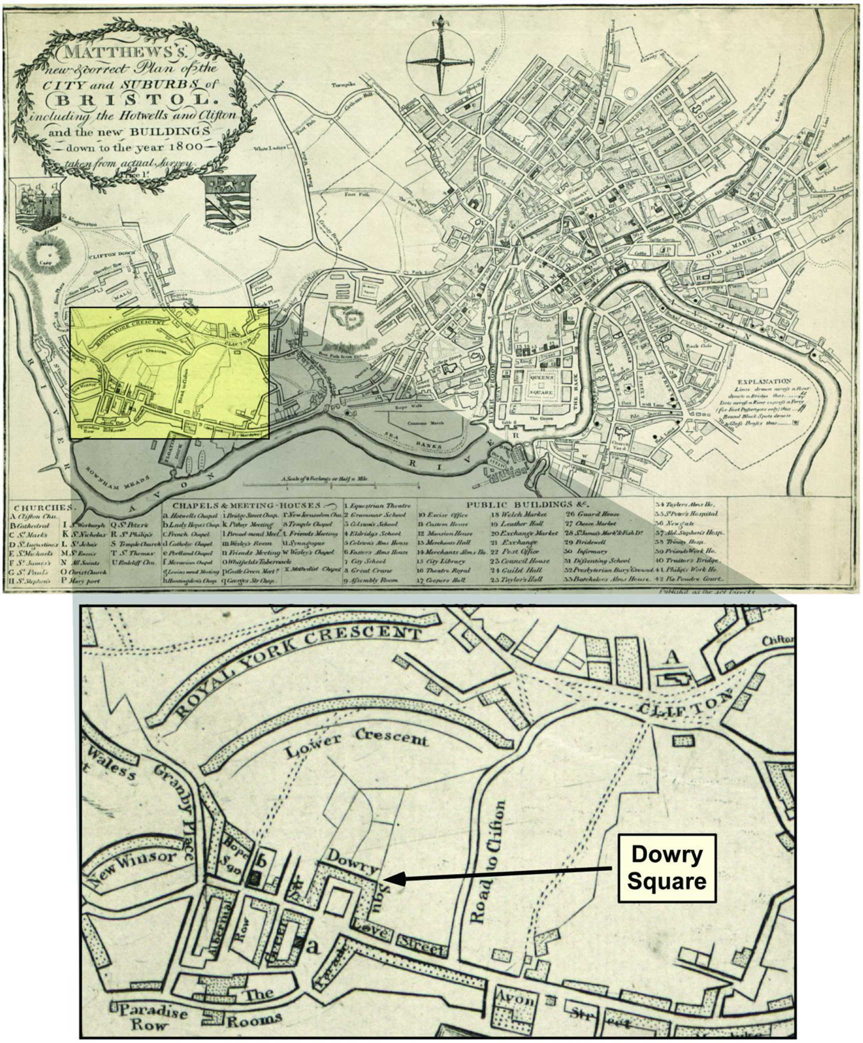


Figure 5. Map of Bristol, 1800. (Courtesy of the Bristol Reference Library).

With the Institution established, Beddoes now required someone to oversee the necessary experiments in the laboratory and Davy had been recommended to fill the position by Davies Giddy (*27*), a mutual friend of both Beddoes and Davy (*13*, *14*, *17*, *20*, *28*). Davy had previously come to Beddoes' attention in April of 1798 when Davy had sent him an account of his early experiments on heat and light entitled "*An Essay on Heat, Light, and the Combinations of Light, with a New Theory of Respiration*", which Beddoes later published in 1799 as part of his collection "*Contributions to Physical and Medical Knowledge, Principally from the West of England*" (*10*, *13*, *14*, *20*, *29*). Beddoes began negotiating with Davy and by mid-September of 1798, the two had come to an informal agreement for Davy's hire (*17*, *28*).

Of course, Davy was still technically legally bound as Borlase's apprentice. However, Borlase resolved the matter in the beginning of October with the following endorsement of Davy's portion of their indenture agreement (*14*, *17*):

> This is to certify that Mr. Humphry Davy served four years of apprenticeship to a Surgeon & Apothecary with me; the last year of his time I give him up, & release him from all engagements whatever, on account of excellent Behaviour, & because being a Youth of great Promise, I would not halt his present pursuits, which are likely to promote his Fortune & his Fame.

Mr. Tonkin, however, was less happy with Davy's decision. He regarded Davy as his successor in Penzance and had fostered Davy from the time that he was five years old, possibly with that succession in mind, and felt betrayed by Davy's choice to give up his medical education (*10*, *13*, *14*, *17*). To counter Tonkin's disapproval, Beddoes argued that the move was to be regarded as a continuation of Davy's medical education, to which Tonkin ultimately gave his grudging assent (*13*, *17*). However, after Davy's departure, Tonkin still felt somewhat wronged. In fact, it has been reported that he actually altered his will, and revoked the legacy of his house which he had previously left to Davy (*13*, *14*).

With the decision finally determined, Davy left for Bristol on October 2nd, 1798 (*10*, *13*, *17*, *29*). Thus, still only 19, Davy began his new position as a researcher for the Pneumatic Institution (*4*, *19*, *22*). Soon after Davy's arrival in Bristol, patients began to be received at the Institution. These patients were treated with both "factitious airs", as well as more commonly accepted medical remedies. At the very infancy of the establishment, however, gases were administered in a smaller proportion of cases than might have been expected from the primary goal of the Institution and were actually rarely resorted to (*28*).

Nitrous Oxide

In the course of his new chemical research on various gases at the Institution, Davy pursued investigations of a gas initially reported by Joseph Priestley (1733−1804) in 1772 (*30–36*). Priestley referred to this gas as *dephlogisticated nitrous air*, while in France it was known as *gaseous oxyd of azote* (*30*, *35*, *36*). In modern nomenclature, however, it would be referred to as dinitrogen oxide (N_2O) or the common nitrous oxide, the latter of which was the name used by Davy (*37–39*). Priestley's original synthesis of the gas involved treatment of iron filings with nitric acid over water (*33*, *34*). The reaction first produces nitric oxide (NO), which was initially isolated by Priestley when the reaction was not carried out over water. However, in the presence of the additional water, the generated NO could further react with water and iron to generate N_2O (*30–35*), as described by the chemical equations below:

$$8\ HNO_3\ (aq) + Fe\ (s) \rightarrow 2\ NO\ (g) + 3\ Fe(NO_3)_2\ (aq) + 4\ H_2O\ (s)$$

$$2\ NO\ (g) + H_2O\ (g) + Fe\ (s) \rightarrow N_2O\ (g) + Fe(OH)_2\ (s)$$

Priestley also reported similar processes using both tin and zinc (*30*, *33*, *39*).

Previous reports on nitrous oxide had resulted in contradictory qualities assigned to it, and the properties of the gas were the subject of much speculation (*35*, *36*). Prior to Davy's work, Priestley had reported warnings about the harmful effects of nitrous oxide and it was generally thought to be highly toxic (*26*, *33*). In addition, Beddoes' American contemporary Samuel Mitchill (1764−1831) had proposed in 1795 that all infectious diseases were caused by the action of nitrous oxide (*16*, *19–21*, *26*). Mitchell argued that life was enhanced by oxygen, but destroyed by nitrous oxide, which he viewed as the opposite of oxygen (*21*, *40*). Reports had also attributed to nitrous oxide a remarkably damaging effect on animal tissue (*31*).

Prior to his work at the Institution, in the summer of 1798, Davy had attempted the synthesis of nitrous oxide via Priestley's methods, but could only generate small volumes of the gas. Using this limited amount of gas, he performed some crude investigations to test Mitchell's theories, including exposing wounds to the gas, immersing animals in it without injury, and even breathing small quantities mixed with air (*16*, *20–22*, *31*, *36*, *41–43*). Davy had sent an account of these early experiments with the gas to Beddoes, which further reinforced Beddoes' ongoing efforts for Davy to join the Pneumatic Institution in Bristol (*22*, *38*, *42*).

After establishing himself at the Institution, he patiently generated larger amounts of the gas and in March of 1799 cautiously attempted breathing a quart or two of the gas mixed with either air or oxygen (*26*, *35*, *38*, *42*, *43*). The gas was not initially fatal, nor were there lasting ill effects, thus casting doubt on its assumed toxicity, but all-in-all the initial results seemed to be inconclusive. The gas appeared to act as a depressant, slowing the pulse and thought to produce a tendency to fainting (*38*, *42*).

Davy continued to investigate the preparation of the gas, finding that in addition to nitrous oxide, the methods also produced *nitrous gas* (nitric oxide or NO) and nitrogen gas as byproducts. The exact amount of the three products depended on the concentration of the nitric acid and the reducing metal applied (*39*). In early April, he tried inhaling a sample of the gas thought to be of higher purity, this time trapping it in an oiled silk bag fitted with a mouthpiece. He then breathed from the bag, exhaling back into the bag with each breath (*38*). Again, however, he was unsatisfied with the results.

Davy then changed his approach and utilized a new method for the preparation of nitrous oxide that had been reported by Claude Berthollet (1748−1822) (*38*). This method involved the thermal decomposition of ammonium nitrate at temperatures between 340 and 440 °C as shown below (*44*):

$$NH_4NO_3\ (s) \rightarrow N_2O\ (g) + 2\ H_2O\ (l)$$

It has been reported that this thermal decomposition was previously described by Joseph Black in 1768, but Black had not identified the gaseous product (*30–32*). In comparison to the previous methods, this now allowed the production of relatively pure nitrous oxide (*44*). Thus, on April 11th, he again prepared to breathe this gas in its purified state.

Davy stated that he was aware of the danger of this experiment, but decided not to attempt initial experiments on animals, as he felt such studies would not differentiate between a toxic gas and an inert gas that simply could not support life (*42*). He thought that the gas would act as a depressant with possible painful effects, but believed that a single inspiration of the gas would "*neither destroy or materially injure the powers of life.*" He thus took a single enhalation of the gas, resulting in "*no uneasy feeling in the lungs*" and convincing him that further studies of its effects could be made without danger (*41–43*).

On April 16th, he then proceeded to breathe a more significant amount of the gas. Without holding his nose and beginning with his lungs full of air, he began to breathe from a silk bag containing three quarts of the gas (*42*, *43*). He continued to do so for more than half a minute, the results of which he described as follows (*42*):

> The first inspirations occasioned a slight degree of giddiness. This was succeeded by an uncommon sense of fulness of the head, accompanied with loss of distinct sensation and voluntary power, a feeling analogous to that produced in the first stage of intoxication; but unattended by pleasurable sensation.

Davy communicated the results to Beddoes and the following day continued the investigation with Beddoes present (*26*, *42*, *43*). This time, he cleared both his nose and lungs of air and then breathed from a silk bag containing four quarts of nitrous oxide. The initial result was similar to that of the previous day, but after about half a minute, the feelings diminished gradually to be succeeded by a sensation analogous to gentle pressure on the muscles. Davy described the experience as follows (*26*, *42*, *43*):

> The objects around me became dazzling and my hearing more acute. Towards the last inspirations, the thrilling increased, the sense of muscular power became greater, and at last an irresistible propensity to action was indulged in; I recollect but indistinctly what followed; I know that my motions were various and violent.

These effects ceased soon after he stopped breathing the gas and within 10 minutes had returned to normal (*38*, *42*, *43*).

Davy continued to investigate the effects of the gas, each time increasing the volume of nitrous oxide and the length of his inhalations (*38*, *42*). He found that breathing the gas for longer periods reduced the violent muscular motions. However, he found that it was difficult to continue breathing the gas for much more than five minutes as by that point "*voluntary power was altogether destroyed, so that the mouth-piece generally dropt from my unclosed lips*" (*42*).

In experiments in which he breathed 10 quarts for nearly four minutes, the sense of slight intoxication lasted for 1−2 hours. In a letter to his friend Davies Giddy (*45*), Davy states that he had just breathed almost 16 quarts for a period of nearly seven minutes and described the experience as follows (*38*, *41*, *43*):

> It appears to support life longer than even oxygen gas, and absolutely intoxicated me. Pure oxygen gas produced no alteration in my pulse, nor any other material effect; whereas this gas raised my pulse upwards of twenty strokes, made me dance about the laboratory as a madman, and has kept my spirits in a glow ever since.

Finally, Davy resolved to breathe the gas for such a time and in such quantities to produce effects equal or superior in intensity to that experienced during strong intoxication from opium or alcohol. This would require a different approach than the previous inhalations utilizing bags of gas. The solution was an "*air-tight breathing-box*" (Figure 6) designed by James Watt (*22*, *41*, *46*, *47*). This was described by Watt as a sedan chair about two and a half by three feet square and five feet high. The walls of the box were primarily composed of paper-covered canvas, the outside of which could be painted for an additional barrier coating. The seat itself was also enclosed so that gas could not collect beneath it. The box contained glass panes on the front and sides for viewing of the patient and two holes which could be sealed with a plug. One hole acted an inlet for the addition of gas and the other an outlet to release pressure as a result of the added gas (*46*).

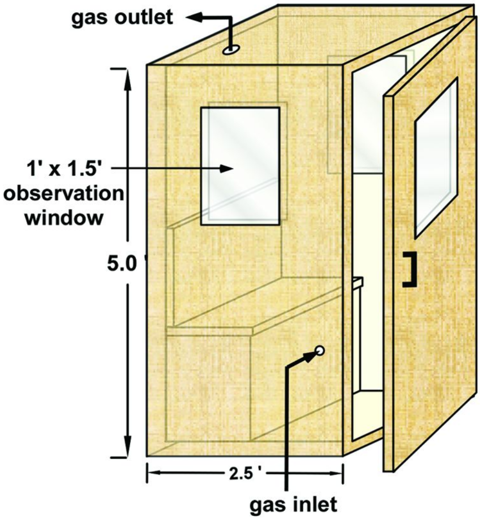


Figure 6. Schematic diagram of the 'air-tight breathing-box' based on Watt's description.

Davy then entered the breathing-box on December 26th, 1799 equipped with a curved thermometer under his arm and a stopwatch, in order to track his body temperature and pulse during the experiment. Twenty quarts of nitrous oxide were then added to the box and Davy breathed this mixture for 15 min. While Davy could smell and taste the nitrous oxide in the box's atmosphere, he noted that it was too diluted with the initial common air of the box to have significant effect, although he did record a slight increase in body temperature. An additional 20 quarts of nitrous oxide was then added to the box, and Davy breathed this more concentrated atmosphere for another 15 min. By this time, both his pulse and temperature had increased, accompanied by pleasant sensations akin to "*a small dose of wine*." (*47*).

A third 20 quart portion of nitrous oxide was then added to the box and he continued to breathe this even more concentrated atmosphere for another 30 min. The pleasurable feelings continued to increase, although his pulse slowed and his body temperature lowered slightly. At this point, a last 20 quart portion of the gas was added and Davy recorded that he now had a great disposition to laugh and that luminous points seemed frequently to pass before his eyes. After spending a total of 75 min in the breathing-box, Davy exited and began to breathe an additional 20 quarts of undiluted nitrous oxide. Davy recorded the effects of this experience as follows (*41*, *47*):

> A thrilling extending from the chest to the extremities was almost immediately produced. I felt a sense of tangible extension highly pleasurable in every limb; my visible impressions were dazzling and apparently magnified, I heard distinctly every sound in the room and was perfectly aware of my situation. By degrees as the pleasurable sensations increased, I lost all connection with external things; trains of vivid visible images rapidly passed through my mind and were connected with words in such a manner, as to produce perceptions perfectly novel. I existed in a world of newly connected and newly modified ideas. I theorised; I imagined that I made discoveries.

When his associate awoke Davy from this semi-delirious trance, he slowly recovered his former state of mind and in an attempt to communicate his experience during the extended experiment, he exclaimed (*22*, *41*, *46*, *47*): "*Nothing exists but thoughts! – the universe is composed of impressions, ideas, pleasures and pains!*"

Nitrous Oxide Concentration and Doses Used by Davy

The nitrous oxide inhaled by Davy had been produced by thermal decomposition of ammonium nitrate which was then allowed to stand for several hours over water saturated with N_2O. This both saturated the gas with water vapor and reduced the possibility of any contamination by nitric oxide, etc. (*38*, *44*). As a consequence, although Davy referred to his respiration samples of nitrous oxide as 'pure', there must have been some contribution to the total volume from water vapor. This of course leads one to the question: What was the actual concentration of nitrous oxide breathed by Davy? Assuming the gaseous mixture had stood over water long enough to reach equilibrium, the amount of water in the mixture would be represented by the vapor pressure of water at a given temperature. Thus, at standard conditions of 25 °C and 1 atm, the vapor pressure of water would be somewhat minimal and the volume of gas should still have been ~97% N_2O (*48*).

Considering that this is still a relatively high concentration of nitrous oxide, it may seem surprising that Davy was able to breathe the volumes as detailed above without consuming a lethal dose. However, contrary to common impressions, nitrous oxide is not lethal when used with adequate oxygen. In fact, a lethal dose of N_2O has been extrapolated to be greater than 525 L! The risk in breathing this gas is not the inhalation of too much nitrous oxide, but of too little oxygen. Known fatal cases from non-medical doses usually involve pure (i.e. 100%) nitrous oxide and death is due to anoxia (i.e. lack of oxygen) (*49*).

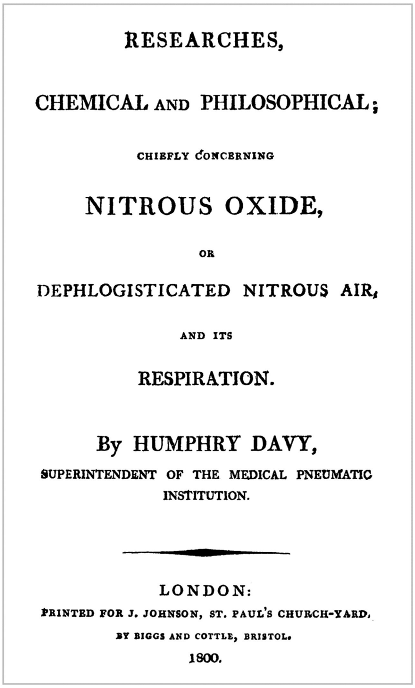
Through experimentation on animals, Davy had found that animals die in atmospheres of N_2O faster than in oxygen or common air, but 2−3 times slower than in atmospheres of non-respirable gases such as hydrogen (*36*, *50*). The modern interpretations of these results is not that nitrous oxide is capable of supporting life in any sense, but that the gas lowers the metabolic rate which could lead to prolonged survival in the gas (*36*). As the human body can survive up to about five minutes without oxygen, it is reasonable to postulate that one could survive 10 minutes or more of breathing pure nitrous oxide. As such, the lengths of time that Davy reported breathing ‘pure’ nitrous oxide (up to seven minutes) were still short enough that any negative effects due to lack of oxygen should have been minimal. In contrast, the elongated time of respiration carried out in the breathing-box experiment was only possible due to the fact that the portions of nitrous oxide were added to the common air initially contained in the box, thus providing Davy with a supply of oxygen.

Public Response and Applications

Davy’s first public announcement about inhaling nitrous oxide was in the *Journal of Natural Philosophy, Chemistry and the Arts* (*51*) and was much more subdued and guarded than the various statements above. He stated that he had inhaled the gas and that “*the effects produced by it were very peculiar*.” He went on to say that if it were possible to confirm the effects, the gas would "*probably prove a valuable medicine.*" (*38*). He again wrote Nicholson a week later asserting that nitrous oxide was indeed respirable when perfectly freed from nitric oxide. This was then followed by a third report noting his alarm “*lest a general notice of the respirability of gaseous oxyd of azote would induce anyone to make injurious experiments on himself.*” Davy promised to follow up with a speedy disclosure of the necessary safety precautions and of any experimental hazards (*38*).

His complete studies on the subject were then published in 1800 as a book entitled *Researches, Chemical and Philosophical; Chiefly concerning Nitrous oxide, or Dephlogisticated Nitrous Air, and Its Respiration* (Figure 7), which brought him immediate fame and notoriety. Davy felt that this publication established him as a full and innovative member of the scientific community, while Beddoes felt its successful publication justified his beliefs concerning the benefits of pneumatic medicine and confirmed the wisdom of Davy’s appointment to the Pneumatic Institution (*38*). Of course, Davy’s reports of the pleasurable and intoxicating effects of the gas soon induced others to try it and sampling of the gas became somewhat popular (*31*, *32*, *35*, *38*, *41*, *52*). This led to its use first as ‘laughing gas’ by popular scientific lecturers (*22*, *53*) and then as a recreational drug among the British upper class (*31*, *32*, *41*). The euphoria brought on by the gas was the principal attraction, with the only real drawback being the cost of its production (*32*). By 1802 the use of the gas had become so popular that French writer Joseph Fiévée (1767−1839) listed it among the various follies to which the English were addicted and stated that the practice of breathing it amounted to a national vice (*41*).

High society's indulgence in nitrous oxide was a rich subject for satire as illustrated by the well-known caricature by James Gillray (1756−1815) showing sampling of the gas during demonstrations at the Royal Institution (Figure 8). In addition to featuring Davy (working the bellows on the right), this caricature features Thomas Garnett (1766-1802) and Benjamin Thompson, better known as Count Rumford (1753−1814). Rumford was the founder of the Royal Institution and is pictured standing by the doorway. Garnett was Davy's predecessor as the Institution's Professor of Chemistry and is shown here as the lecturer (*4*, *52*).



RESEARCHES,

CHEMICAL AND PHILOSOPHICAL;

CHIEFLY CONCERNING

NITROUS OXIDE,

OR

DEPHLOGISTICATED NITROUS AIR,

AND ITS

RESPIRATION.

By HUMPHRY DAVY,
SUPERINTENDENT OF THE MEDICAL PNEUMATIC
INSTITUTION.

LONDON:
PRINTED FOR J. JOHNSON, ST. PAUL'S CHURCH-YARD,
BY BIGGS AND COTTLE, BRISTOL.
1800.

Figure 7. Title page of Davy's Researches, Chemical and Philosophical; Chiefly concerning Nitrous oxide, or Dephlogisticated Nitrous Air and Its Respiration (1800).

In terms of its potential medical applications, Davy described using the gas to relieve headaches and physical pain (*37*). In addition, he reported that nitrous oxide provided relief of headache and depression resulting from overindulgence of alcohol (*43*, *54*). Finally, in the conclusion of his *Researches*, he went so far as to propose (*32*, *55*):

> As nitrous oxide in its extensive operation appears capable of destroying physical pain, it may probably be used with advantage during surgical operations in which no great effusion of blood takes place.

However, this recommendation was largely ignored and the modern use of nitrous oxide as an anesthetic was not demonstrated until 1844 (*31*, *32*). The lack of interest in its application as an anesthetic has been postulated to be due to the fact that at this point in time, the attention of British physicians was monopolized by the prevalence of pollution-induced chest diseases and thus no one was seeking to eliminate pain (*53*).

Figure 8. Scientific Researches!—New Discoveries in Pneumaticks!—or—an Experimental Lecture on the Powers of Air, 1802, James Gillray, British, Hand-colored etching on wove paper. (Gift of Fisher Scientific International, Chemical Heritage Foundation Collections, Photograph by Gregory Tobias, Courtesy of the Chemical Heritage Foundation Collections).

Over 40 years later, a Hartford, Connecticut dentist named Horace Wells (1815−1848) sampled the gas during its demonstration and realized its potent analgesic action. Wells himself then became the first patient to be operated on under anesthesia, during the extraction of one of his teeth in December of 1844 (*53*). While he then began using it on his own patients, it was not in common use as such until the 1870s, by which time other substances had also become available (*32*).

Pneumatic Investigations of Other Gases

In August of 1799, Davy began investigating the respiration of other known gases in an attempt to determine if there were relationships between the effects of these gases and the effects of nitrous oxide (*56*). He began with the respiration of four quarts of hydrogen, produced via the reaction of zinc and muriatic acid (HCl) as shown below:

$$Zn\ (s) + 2\ HCl\ (aq) \rightarrow H_2\ (g) + ZnCl_2\ (aq)$$

However, Davy was compelled to stop after only about a minute due to the pain of suffocation. He reported that he felt no giddiness during or after the experiment, with the only measurable effect being purple cheeks and a feeble and quickened pulse (*56*, *57*).

Next, he attempted to breathe three quarts of nitrogen, which he said was mingled with a very small portion of '*carbonic acid*' (CO_2). Although Davy does not say how the gas sample was generated, nitrogen is generally isolated from common air. During this time period, this was typically accomplished via conversion of the oxygen content to CO_2 via combustion of a carbon source and then removal of the CO_2 by passing the gaseous mixture through water (*58*). Such methods would produce samples consistent with Davy's description above. As with hydrogen, attempts to breathe nitrogen resulted in a painful sense of suffocation that grew after the first 20 seconds and forced him to stop before the end of the first minute. Again, no measurable effect other than a similar change in pulse (*56*).

He then moved on to more dangerous territory with investigations of *hydrocarbonate* (a near equal molar mixture of carbon monoxide and hydrogen, now referred to as *water gas* or *synthesis gas*). Hydrocarbonate is produced by passing steam over red-hot charcoal (*41*, *56*, *59*), as represented by the reaction below:

$$C\ (s) + H_2O\ (g) \rightarrow H_2\ (g) + CO\ (g)$$

In addition to carbon monoxide and hydrogen, the gaseous mixture produced in this way often contains amounts of carbon dioxide and residual water vapor as well (*58*). Previous reports of human respiration of diluted samples, as well as Beddoes' own animal experiments with pure hydrocarbonate, had proven that its effects were quite harmful (*56*, *60*). In his first attempt, Davy utilized a mixture of three quarts of hydrocarbonate and two quarts of air (*56*, *57*, *60*). Respiration of this mixture for nearly a minute produced a slight giddiness and pain in the head, as well as a momentary loss of voluntary power. As before, his pulse also quickened and became feeble. These effects, however, faded within five minutes of breathing normal air (*56*, *60*).

Davy thought these effects compared well with those experienced with his first inhalations of nitrous oxide and thus resolved to breathe pure hydrocarbonate (*56*). Thus, preparing a silk bag containing four quarts of nearly pure hydrocarbonate, he exhaled the air from his lungs, closed his nose and made three inhalations of the gas. The first breath produced numbness and loss of feeling in the chest. After the second breath, Davy lost all perception of his surroundings and had no distinct sensation except "*a terrible oppression on the chest.*" The final breath caused Davy to feel that he was "*sinking into annihilation*" and he had just enough power to drop the mouth-piece from his lips (*56*, *60*). After a short interval of breathing common air, his surroundings became distinguishable and he was able to faintly say "*I do not think I shall die.*"

Within a minute, he was able to get up and stumble outside to the garden. At this point, he reported that the painful feeling in his chest increased to the point that he thought he would suffocate and he asked his assistant for some nitrous oxide. After breathing a mixture of nitrous oxide and oxygen for a minute, he felt better, and after five minutes the pain began to diminish. An hour later, the pain had nearly disappeared, though he still felt excessively weak. Later, however, the giddiness returned with such violence that he was forced to take to his bed before suffering from nausea, loss of memory and deficient sensation. The giddiness was then replaced with an excruciating headache and transient pains in the chest and extremities. Davy reports that he had every reason to believe that if he had taken one or more inhalations of the hydrocarbonate, he would have died immediately without producing any painful sensations (*56*, *60*).

Approximately a week after his experiments with the carbon monoxide mixture, Davy decided to continue with his investigation of the other gases, this time focusing on carbon dioxide. Davy produced the desired gas via thermal decomposition of ammonium carbonate, as shown below:

$$(NH_4)_2CO_3\ (s) \rightarrow 2\ NH_3\ (g) + H_2O\ (l) + CO_2\ (g)$$

The resulting gaseous mixture was then passed through water to remove the ammonia by-product. After completely emptying his lungs, Davy then attempted to breathe from a silk bag containing four quarts of well-washed carbon dioxide (*56*). The gas tasted strongly acidic in the mouth and produced a sense of burning at the top of the uvula. The acidic response of the inhalation was presumably due to the reaction of the carbon dioxide gas with the water in his mouth and throat, resulting in the formation of carbonic acid (H_2CO_3) as shown below:

$$CO_2\ (g) + H_2O\ (l) \rightarrow H_2CO_3\ (aq)$$

Attempts to draw the gas into the windpipe induced a painful stimulation resulting in his throat to spasmodically close and thus Davy was unable to get any of the gas into his lungs (*56*, *60*).

Davy then tried diluting three quarts of carbon dioxide with two quarts of common air, but attempts to breathe the diluted mixture produced the same results. Further diluting three quarts of CO_2 with seven quarts of common air finally resulted in a suitable mixture that he was able to breathe for nearly a minute. The reported effects were a slight degree of giddiness and an inclination to sleep, both of which disappeared with a return to normal air (*56*, *60*).

Having previously worked with nitric oxide in the process of studying nitrous oxide, and finding no painful effects produced by the application of the gas to bare muscular tissue, Davy imagined that it might be safely breathed, providing that it was possible to free the lungs of common air before inhalation (*56*, *60*). This way the possible formation of nitrous acid (HNO_2) via the reaction below could be prevented:

$$2\ NO\ (g) + H_2O\ (l) + \tfrac{1}{2}\ O_2\ (g) \rightarrow 2\ HNO_2\ (l)$$

To test this, Davy prepared three vessels; one containing a little under two quarts (114 in^3) of nitric oxide and the other two containing a combined total of seven quarts of nitrous oxide (*56*, *60*). After emptying his lungs, Davy inhaled nitrous oxide from one of the containers three times in order to free his lungs of as much oxygen as possible. Then, after completely exhaling the nitrous oxide, he attempted to take a breath from the container of nitric oxide.

As Davy began inhaling the gas, "*it tasted astringent and highly disagreeable*," causing a burning in the throat and producing a spasm of the epiglottis so painful that he immediately stopped the inhalation. Upon opening his mouth to breathe common air, nitrous acid was instantly formed in his mouth, burning his tongue and palate, injuring his teeth, and producing an inflammation of the mucous membrane that lasted for hours (*56*, *60*).

Davy reasoned that even after purging his lungs with nitrous oxide, a small amount of residual air still remained which reacted with the nitric oxide to produce nitrous acid. In the end, Davy felt grateful that the nitrous acid formation began in this mouth, as this stopped him from inhaling the gas into his lungs where the formation of nitrous acid could have been much more damaging (*56*, *60*). Davy swore "*I never design again to attempt so rash an experiment.*"

The Royal Institution and a Change in Direction

In October of 1799, with his inhalation experiments completed, Davy became ill. Davy blamed this illness on "*the constant labour of experimenting, and the perpetual inhalation of the acid vapours of the laboratory*" (*38*). In order to recuperate from his illness, Davy returned to Penzance for a period of convalescence (*38*, *41*).

Davy returned to Bristol on November 27th and began finishing up various loose ends on his nitrous oxide experiments (*41*). The following year he wrote his book on nitrous oxide, with the manuscript nearly complete by June 5th. At the same time, Beddoes and Davy began to be at odds with one another due to disagreements over the interpretation and importance of experimental data. In January 1801, Davy was entertaining proposals to leave the Pneumatic Institution for the Royal Institution established by Count Rumford in London (*26*, *61*). Negotiations continued and were finalized by February 16th, 1801, when the following resolution was adopted at the Royal Institution (*61*):

> Resolved - That Mr. Humphry Davy be engaged in the service of the Royal Institution, in the capacities of Assistant Lecturer in Chemistry, Director of the Laboratory, and Assistant Editor of the Journals of the Institution, and that he be allowed to occupy a room in the house, and be furnished with coals and candles; and that he be paid a salary of one hundred guineas per annum.

Davy returned to Bristol to hand over his charge of the Pneumatic Institution, made his farewells and formally moved to the Royal Institution on Wednesday, March 11th, 1801. Following Davy's departure, the Pneumatic Institution struggled on for a while, but ultimately failed (*61*). By 1803, it had transitioned to a more conventional establishment for the relief of the sick, and was now known as the Preventative Institution (*19*, *62*).

Sometime during the writing of his book on nitrous oxide in 1800, Davy realized he had become addicted to the gas (*16*, *26*, *46*). Considering that he had been inhaling it constantly for a number of weeks, often several times a day, this is perhaps not surprising. Davy stated that (*16*):

> I ought to have observed that a desire to breathe the gas is always awakened in me by the sight of a person breathing, or even by that of an air-bag or an air-holder.

In contrast to most drugs of addiction, however, nitrous oxide does not develop a physical dependence. As a consequence, Davy appears to have easily broken himself of his dependency once he moved to the Royal Institution and to a different field of research (*16*, *46*).

At the Royal Institution (Figure 9), he resumed work on electricity that he had initiated in Bristol and after reading of Berzelius' work on electrolysis, he began investigating the electrolysis of potash. As a result, he discovered potassium metal on October 6, 1807 (*4*, *63*), and sodium was discovered from the electrolysis of soda a few days later. Davy continued to electrolyze different molten salts and also discovered strontium, calcium, barium, and magnesium (*4*, *6*). Of course, this was just the beginnings of his significant contributions to chemistry and in the process, he turned the Royal Institution into a center for advanced research with a reputation for polished demonstration lectures delivered to audiences populated by fashionable gentlemen and ladies.

Although he continued at the Royal Institution for essentially the remainder of his career, he did register as a Fellow Commoner at Jesus College, Cambridge on July 3rd, 1804, apparently with the purpose of gaining a medical degree (*10*, *21*). His motivation for this action is unknown and it did not seem to lead to anything. As this was before his landmark discovery of sodium and potassium, it is possible that he was unsure as to the long-term security of his career as a Professor of Chemistry. However, it is also possible that he still felt some lingering obligation to finish his medical education for Mr. Tonkin. In the end, we may never know and it only provides an interesting point of speculation.

Figure 9. Humphry Davy while at the Royal Institution at age 24. (1803 Portrait by Henry Howard © National Portrait Gallery, London).

Epilogue

The presentation of Davy's early career above leaves little doubt about his rightful place as a 'character' of chemistry. However, in addition to the entertaining aspects of Davy's more colorful studies in pneumatic chemistry, what have we learned about the nature of science from Davy's story? The following points about the scientific process could all be made while using Davy as an example:

i. ***The greatest discoveries are not always made by the most highly trained or highly educated people.*** Davy was essentially self-taught, with no university training, yet made tremendous contributions to science. While significant discoveries by self-taught investigators would be less common today, the most successful modern scientists are still not necessarily always those that attended the most prestigious schools or received the best training and discovery always involves a certain amount of luck. Of course, asking the right questions and pursuing the right experiments always helps as well.

ii. ***Taking risks can pay off (but they can also kill you!).*** Davy's decision to inhale nitrous oxide when everyone believed it to be toxic was quite a risk, yet this resulted in a significant discovery and the start of his noteworthy career. Of course, at the same time, his decision to inhale other dangerous gases nearly killed him. Although modern safety regulations attempt to limit the types of physical risks taken by scientists, risk is still a large part of the pursuit of science, be it physical, intellectual, or monetary. Successful scientists will often bet their future on ideas that counter current dogma or that most colleagues would consider a long shot at best. Funding agencies in particular often look for research proposals that target "high-risk, high-reward" ideas.

iii. ***Discoveries are really never due to a single person, but are just the next step in the pursuit of understanding.*** While the discovery of the biological effects of nitrous oxide is credited to Davy, it depended on the previous work of Priestley and Berthollet, as well as collaborations with Beddoes and Watt. In modern scientific research, almost all work is carried out by research groups of students, postdoctoral researchers, and technicians under a more senior scientist, rather than the individual efforts of the 1800s. However, the same general principle still holds true and the advancements reported by one such research group depends critically on the previous work of other such groups. As chemistry Nobel Laureate Alan MacDiarmid put it: We all owe so much to those who have gone before us – "*we stand on the shoulders of giants.*" (*64*).

iv. ***A discovery in one area of science can often lead to new discoveries in other areas.*** It was the discovery of gases such as oxygen, carbon dioxide, and hydrogen that provided a new chemical framework for Beddoes and others to investigate the possible medical applications of these gases.

v. ***Success can open doors or provide opportunities to greater success.*** Without Davy's success with the study of nitrous oxide, he most likely would not have been offered the position at the Royal Institution, which then allowed him even greater success with the isolation of various elements such as sodium and potassium. In modern science, not only can success provide the possibility of better research positions, but also increases the ease of getting future work published and funded.

vi. ***It is important to take advantage of the opportunities that are available to you.*** Davy made the decision to give up his apprenticeship with Borlase and the security of a career as a surgeon and apothecary in order to pursue chemical research at the Pneumatic Institution. This single decision started a path that led to his eventual success in chemistry.

While Davy provided the world with a number of highly significant chemical discoveries, this hopefully illustrates how his life story and his 'character' also provide us with a greater understanding of the pursuit of science and those that strive to become sons of genius.

From Davy's 1795 poem *Sons of Genius* (*13*):

For those exist whose pure ethereal minds,
Imbibing portions of celestial day,
Scorn all terrestrial cares, all mean designs,
As bright-eyed eagles scorn the lunar ray.
Theirs is the glory of a lasting name,
The meed of Genius and her living fires,
Theirs is the laurel of eternal fame,
And theirs the sweetness of the Muse's lyres.

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is anticipated. Their American brethren heartily wish the enterprising and indefatigable gentlemen success in their labours. Such zealous and amicable cooperation between the votaries of science on both sides of the Atlantic promises abundance of good." See reference 19.

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Chapter 8

Historical Chemists in Fiction

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Chemists are rarely the protagonists in published works of fiction. Exceptions to the above statement are the subject of this chapter. Chemists appear in fiction as solvers or perpetrators of crime, as producers of riches, as people in love, and occasionally as scientists. After a brief overview of chemical characters in the non-chemical literature, the chapter focuses on a still narrower class, namely historical chemists who appear as characters in works of fiction.

Introduction

Chemists or people trained in chemistry have long been staples in detective fiction, on both sides of the law (*1*). Among the first appearances of Sherlock Holmes, the world's first consulting detective, are references to chemical knowledge and tests. The first meeting between Holmes and Watson takes place in the chemical laboratory of a hospital, where Holmes is working on a test for the detection of blood (*2*). References to Holmes's test tubes appear in several other works of the Holmesian canon as well; however, the glassware plays no directly relevant part in the plots of those works (*3*). Using chemical knowledge to commit crimes or destroy evidence is also common in crime fiction. The culprit in Dorothy Sayers's *Strong Poison* is an arsenic eater, one who has built up a tolerance that his victim does not share (*4*). Henry Lakington, a brilliant scientist before he turned to crime, is a pantomine villain in Herman Cyril McNeile's, *Bull-Dog Drummond*. Cruel, vindictive, and cowardly, Lakington puts his knowledge of poisons, incapacitating gases, and a solution that can dissolve a corpse in a matter of minutes at the disposal of a criminal kingpin (*5*).

An even older fictional theme in which chemists and chemistry are sometimes portrayed involves variations on the Midas myth: riches from dirt, thin air, or base

In Characters in Chemistry: A Celebration of the Humanity of Chemistry; Patterson, G., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

metals. Ben Jonson's comedy *The Alchemist* was first performed more than 400 years ago. The title character, Subtle, is a charlatan who pretends to be able to produce gold. He talks the talk of the chymistry of the time to reel in his greedy client (*6*). In 1891, Arthur Conan Doyle portrayed a latter-day alchemist, Raffles Haw, who really *could* make gold from lead (in the story) by passing electricity through it; however, despite Haw's good intentions, no good came of it (*7*). Other authors invoked the transforming power of chemistry to turn humble materials into valuable commodies other than precious metals or gems. For example, in *Sugar in the Air* (*8*), the scientists and engineers exert much effort to develop an economically viable process to manufacture sugar from the air, but the enterprise is eventually doomed by the incompetence and venality of the company's board of directors. In *The Sun Chemist* (*9*) the goal is a biofuel that would displace gasoline, a process that oil interests attempt to suppress.

Ian Rae's article "Dustcoats in Dustjackets" (*10*) is an excellent but now somewhat dated source of books and stories in which chemists appear as plot devices or as substantial characters. Rae mentions and cites no fewer than 70 works of fiction in which chemists or at least people who appear to use chemistry play significant parts in the narrative. The characters Rae treats range from cardboard cut-outs serving largely as props to complex characters in serious attempts to depict science and scientists in action. The works he mentions date back to the 17th century and up to the late 1970s.

One genre Rae treats only lightly is science fiction. Readers curious about chemists in that genre will find several essays in *Chemistry in Science Fiction* (*11*) of interest. Edited by Jack Stocker, the book is based on a 1992 ACS symposium on the subject. As the title suggests, the book is more focused on chemistry than on chemists, but it does include plenty of chemists as characters, science fiction authors, and authors of the book's essays.

A fictional genre not treated by Rae at all is the love story or romance novel. A search of the international library database WorldCat (*12*) for chemists in fiction turns up a surprising number of entries in this genre from publishers such as Harlequin and series such as Woman's Weekly Library. Many of the titles turned up in the search contain no indication that chemistry of any kind other than romantic is involved or that any of the characters might don a lab coat by day; the subject heading "Chemists--Fiction" in the bibliographic record is the only clue. In *Chemistry for Beginners*, however, chemistry but not romance is clear from the title. It is a light romantic comedy in which a stereotypically nerdy male researcher and a beautiful and intelligent female research subject stray humorously off protocol (*13*).

Chemists are occasionally portrayed as scientists—as real human beings who attempt to comprehend at least some aspects of how nature works. The depiction of scientists engaged in realistic science tends not to top best-seller lists; however, works of this sort have been published, discussed, and compiled in some lists. One term for this sort of literature is Lab Lit, in which "realistic" scientists are the protagonists, "fairly realistic" scientific ideas or practices are described, and the setting is also "realistic" as opposed to futuristic or speculative. Jennifer Rohn, whose day job is as a microbiologist, edits the website LabLit.com, "dedicated to real laboratory culture and to the portrayal and perceptions of that culture—science, scientists and labs—in fiction, the media and across popular culture" (*14*). One of the site's features is a list of published Lab Lit fiction (*15*).

(Realistic portrayals of scientists, or at least portraits that scientists would recognize as realistic, are more the exception than the rule in fiction written for a general audience. Readers interested in a scholarly study of how scientists are portrayed in popular fiction are directed to Roslynn Haynes's *From Faust to Strangelove* (*16*). Subtitled "Representations of the Scientist in Western Literature," the book classifies several types of scientists as depicted in popular fiction. Haynes argues that the number of actual scientists that most members of the general public can name is minuscule. Furthermore, the scientists she names (Newton, Einstein, and Curie) are hardly typical specimens. Haynes argues that fictional characters including "Dr. Faustus, Dr. Frankenstein, Dr. Moreau, Dr. Jekyll, Dr. Caligari, and Dr. Strangelove" contribute more than accounts about actual scientists to popular stereotypes of scientists. One of the types discussed, the alchemist, is specific to chemistry (or rather to chymistry), and many of the others could in principle apply to chemists. In addition to the book's primary subject (analysis of scientific characters into types), readers will also find its bibliography a rich source of fictional works featuring scientific characters.)

A genre closely related to Lab Lit is science-in-fiction, a term used by chemist, novelist, and playwright Carl Djerassi. He draws a sharp distinction between science-in-fiction and science fiction: in the former, "all aspects of scientific behaviour and scientific facts are described accurately and plausibly" (*17*). He makes the point that "the cloak of fiction" permits writers to take up ethical dilemmas and other aspects of the lives of scientists without giving offense to or fearing retribution from real people.

Djerassi's own novels and plays are examples of the chemical branch of this genre. For example, *The Bourbaki Gambit* portrays researchers who develop a ground-breaking biochemical technique, namely the polymerase chain reaction (PCR). They publish their results, as was their habit, under a pseudonym, but this paper is too important for the anonymity of pseudonymity (*18*). C. P. Snow is perhaps the classic author of science-in-fiction (before the term was coined). His early novel *The Search* describes the life of Arthur Miles, an X-ray crystallographer whose career crumbles on the very threshold of a triumph (*19*). (Miles works in a physics department, but his research is close enough to chemistry for the purposes of this paper.)

Readers interested in finding chemical Lab Lit have several resources at their disposal, although none is quite definitive. The Lab Lit List is current, but most of its entries are not chemical. Rae's article is focused on chemistry, but it includes fiction outside the Lab Lit definition, and it is more than 30 years old. WorldCat is current, but searching for the subject heading "Chemists--fiction" also yields suspense and romance fiction. Walter Gratzer's anthology, *A Literary Companion to Science*, is another excellent resource not yet mentioned (*20*). It contains excerpts from factual and fictional portrayals of scientists, including chemists. The passages in Gratzer's book are from works in which science is the main topic or scientists the main characters rather than peripheral ones or plot devices. So the book is all about Lab Lit, but it is not all fiction and certainly not all chemical. Chemistry in what might be called serious literature was Philip Ball's topic in the

December 2008 issue of *Chemistry World* (*21*). (Serious literature is my term, not Ball's; I only mean to exclude clearly escapist literature.) Ball concentrates on fiction with some mention of memoir. Some of the works Ball treats qualify as Lab Lit, but by no means all do. Indeed one, Goethe's *Elective Affinities*, has no chemists, but chemistry is its overarching metaphor.

Historical Chemists in Fiction

The remainder of this chapter focuses on a subset of chemists in fiction appropriate for a chapter in a volume on historical characters in chemistry, namely historical chemists portrayed as important characters in fictional works. Before discussing these examples in some detail, I briefly mention some instances that fall just outside this focus. On the one hand, historical figures of all sorts can appear in works of fiction without being significant characters. Examples can range from mere stray mentions as of Humphry Davy in *Middlemarch* (*22*), occasional mentions as of Lavoisier in *The Quest of the Absolute* (*23*), or repeated mentions as of Davy in *Journey to the Centre of the Earth* (*24*). On the other hand, one can also find significant characters that are disguised versions of historical figures—sometimes thinly disguised versions. Gratzer (*20*) often comments on the resemblances between historical and fictional scientists, including the autobiographical elements between character Arthur Miles and author C. P. Snow in *The Search*.

So the rest of the chapter focuses on historical chemists who appear as significant characters in fictional works under their own names. The works to be discussed fall into two main groups, biographical fiction and more imaginative historical fiction. In the former, the lives of the historical protagonists, or at least some key episodes in their lives, are the focus of the book. The latter is a less internally coherent category, defined mainly by contrast with the former.

Biographical Fiction

Joseph Priestley: LL.D., F.R.S.

The most straightforwardly biographical of these books is a 1954 historical novel by John Graham Gillam called *The Crucible* (*25*). In several ways, it is more like a work of biography or history than of fiction. Among its similarities to factual or even scholarly works is the highly formal subtitle, including the honorific initials to which Priestley was entitled. It has a brief bibliography, which is not all that unusual for novels that have some factual basis. More unusual for a novel, it also has an index. And it has illustrations that would be appropriate in any factual account of Priestley's life, including reproductions of a portrait of Priestley and of a cartoon depicting him as Dr. Phlogiston (Figure 1). The book's pages are even headed by guide years (analogous to the guide words of a dictionary) to keep the reader aware of when the actions described took place.

The narrative is strictly chronological, spanning 1772, when Priestley entertained Lord Shelburne's offer of patronage, to 1794, when he landed in

America. The fiction here is more embellishment or fleshing out of scenes than invention out of whole cloth. For example, much factual information and many historically documented opinions are conveyed through invented dialogue. Although the narrative is third-person, it is distinctly from Priestley's perspective. The reader learns nothing that Priestley's character does not see, hear, or read.

The story includes Priestley's discovery of the air he called dephlogisticated, but it devotes more attention to political and religious topics than to scientific ones. Considerable ink is devoted to the relations between the American colonies and the British government, and Benjamin Franklin is another important character. Much attention is also paid to the Birmingham riots of 1791, which destroyed Priestley's house and sent him and his family fleeing for their lives.

Figure 1. DOCTOR PHLOGISTON, The PRIESTLEY politician or the Political Priest, engraving by "Annabal Scratch," published by Bentley & Co., July 1, 1791. From Library of Congress, Prints & Photographs Online Catalog (http://www.loc.gov/pictures/item/2006692323/).

Priestley's character is idealistic, even other-worldly. He is deeply religious, confident in Providence, devoted to social justice, and not very concerned about receiving his due. (When Lord Shelburne tells him indignantly of Lavoisier's paper on vital air, Priestley replies, "Surely it matters not, my lord, who claims to be the discoverer.") This last point contrasts somewhat with another fictional portrayal of Priestley to be treated below.

Three Sisters and Three Chemists

The Holland Sisters (*26*) is also fairly straightforward biographical narrative, but much less formal than *The Crucible*. The protagonists are three sisters who married three chemists, all of whom were prominent British chemists of the early 20th century. The sisters are Mina, Lillian, and Kathleen Holland of Bridgwater, Somerset, England. They are shown in their old age on the book's cover. They married, respectively, William Perkin, Jr., Frederic Kipping, and Arthur Lapworth. As the title suggests, the sisters really are the main characters—especially the middle sister Lily. The book is in this chapter, however, because their husbands (the chemists) are important supporting characters.

The authors describe the work as a biographical novel that sticks to historical fact where known and uses other details from the period where the facts are unknown. After all, the lives of the women were not nearly so well documented as those of their husbands. For example, Lily's life as a girl at boarding school is described using details recorded by other young women of the same time and class. The authors, who include the celebrated silicone chemist Eugene Rochow, had help from Kipping's grandson, Brian Kipping. Indeed, silicones are a link between the author Rochow and the historical chemist and character Kipping.

The writing, unfortunately, is not of the highest caliber, tending at times toward insipidity. The characters, with the possible exception of Lily, are not strongly drawn. William Brock has written about this book (*27*), describing its value in providing a rare look at the family lives of chemists but warning readers not to expect much in the way of literary merit. He calls the dialogue stilted and didactic, and I must agree—and not only the dialogue. For example, the sisters hold a mini-colloquium on Kipping's newly discovered silicones in a railway compartment on the way back from their mother's funeral. A non-dialogue example is a sketch of the career of Benjamin Thompson, Count Rumford, via recollected conversations Mina had had with her husband. The most genuinely and skillfully conveyed insight of the book is the pleasure that all of its protagonists had in music. In the end I also agree with Brock's assessment that the book is worth reading despite its shortcomings.

Three Farflung Brothers

After three sisters, we consider three brothers in another 2001 biographical novel, *The Brothers Carburi* (*28*). This book features strong characterization conveyed in a light and familiar tone, making for a pleasant reading experience.

The storytelling technique is sophisticated, accomplished in small snippets of narrative that hew mainly to chronological order with occasional jumps ahead and frequent looks back in time. The actual accomplishments of these obscure brothers make an interesting story. The fact that the events are set somewhat away from the beaten track of the accounts of Enlightenment science with which I am familiar (mainly in Northern and Western Europe) supplied me with additional interest due to novelty. Figure 2 displays the geographical extent of the story.

The main characters are the first three sons born to the Carburi family in the 18th century on the Greek island of Cephalonia: first Giovanni Battista, then, in quick succession after a long interval, Marino and Marco. (The family also had a daughter, Maria, and another son, Paulo, whose roles in the story are minimal.) Cephalonia was a territory of the Republic of Venice at the time. Italian was the language of school and most public life, Greek the language of the Orthodox church and the characters' childhood home. All three brothers left Cephalonia as young boys for boarding school and later university on the Italian mainland.

Marco, the chemist, is the least interesting of the three. He studied medicine at Padua and then turned his attention to chemistry. He followed his professor Iacopo Bartolomeo Beccari to Bologna, and at age 28 was called to a new chair in experimental chemistry at Torino. Soon thereafter, he was sent on a tour of mines in eastern Europe and Scandinavia in hope (unrealized) of improving yields in Venetian mines. Later he developed a completely combustible paper for packaging gunpowder charges, for which the Venetian republic honored him by striking a medal. Late in life, he was skeptical of the new chemistry championed by Lavoisier.

Giovambattista, the eldest, studied medicine at Bologna and became Professor of medicine at Torino. He prospered there, earning appointment as physician to the daughter of the King of Sardinia and Piedmont. As a physician to the royal household, he made a tour of Great Britain and the Low Countries, and he was elected Fellow of the Royal Society in 1765 (a year before Priestley, by the way). When his royal patient married the brother of the heir of the French king, Carburi moved to Paris, where he lived through the French Revolution. He was characterized as serious, responsible, discreet, somewhat pompous, and highly loyal.

Marino, by contrast, was passionate and indiscreet, but also very loyal and (when he wanted or needed to be) as meticulous and intelligent as his brothers. He is the book's principal protagonist, its most complex and interesting character. As a young man he fled Venice after he fatally strangled a woman with whom he was romantically involved. With money and contacts from Giambattista, he went to Vienna, and he changed his name to Alexandre, Chevalier de Lascaris. Eventually he made his way to St. Petersburg. While in Russia, he carried out the great engineering feat of extracting a 3-million-pound monolith from a swamp and transporting it to St. Petersburg, where it forms the base of the equestrian statue of Peter the Great. That is, he engineered the methods and machinery for carrying out this task and supervised its execution. Later he returned to Cephalonia, where he drained a swamp and attempted to grow cotton, indigo, and sugar cane. He and most of the other inhabitants of his household were murdered during this agricultural experiment.

Figure 2. Outline map of Europe displaying key locations in The Brothers Carburi.

Psychological Biographical Fiction

The next two books are also in the biographical realm, but they have a strong psychological bent.

A Chemist as Spy

Millicent Dillon is the author of several non-fiction biographies. In *Harry Gold* (*29*), though, she tries to get inside her subject's head, imagining how he felt as he carried out his espionage. The historical Gold is best known as the contact through whom Los Alamos scientist Klaus Fuchs passed nuclear secrets to the Soviet Union. In the novel and in fact, Gold's chemical knowledge and contacts were relevant to his early spying activities, but irrelevant to his contact with Fuchs. In his interactions with Fuchs, Gold was simply a courier who got on Fuchs's nerves. Gold was recruited into espionage by a friend from a lab job who helped him get another job in another lab when Gold was laid off during the Depression. The first information that Gold passed to the Soviets was about chemical industrial processes from the company where he worked. During World War II, one of Gold's assignments was to obtain information about the manufacture of the synthetic rubber Buna-S from a flighty genius, Sid Roth. After the war, Roth employed Gold as a chemist at his small consulting company after a chance meeting.

The last few pages of the book quote extensively from the statement of Gold's attorney before sentencing. (Gold pled guilty and had not made a plea bargain.) The attorney described Gold's actions as those of a selfless but misguided man. Based on the portrait from the rest of the book, this was an oversimplification. It is fair to say that the Gold depicted in the book never had the intent to harm the US. Rather, it seems to me that the character Dillon described was too weak to say no to requests to help others—such as the poor citizens of the Soviet Union trying to make a better society for themselves after throwing off Czarist oppression and later the suffering and heroic Soviet people who helped the US defeat the Nazis. Gold occasionally reflected about deception and reality, but seldom if ever were his own thoughts the impetus for the actions described in the book.

Marie Curie and the "Queen of Hysterics"

The final biographical novel treated here, *The Story of Blanche and Marie* (*30*), has less narrative and more psychology than *Harry Gold*. From the cover, one might wonder if it is one of the bodice rippers alluded to in the Introduction. Well, not really, although love and desire are central to the book. The cover is a detail from a painting of a lecture demonstration at the Paris hospital, the Salpêtrière. The woman in the painting (Figure 3) is Blanche Wittman, who was confined to the hospital for 16 years for "hysteria." The speaking man standing next to her is Jean-Martin Charcot, Professor of Pathological Anatomy of the Paris Medical Faculty and later Professor of Diseases of the Nervous System. Wittman was known as the queen of the hysterics, and she was often the star of Charcot's lecture-demonstrations to medical students (*31*). They are two of the main characters in the book. The third is Marie Curie. In fact, Wittman worked as an assistant of Curie a few years after she was released from the Salpêtrière after the death of Charcot.

In the book, Wittman is a multiple amputee, having lost deteriorated limbs to radiation exposure. She lives with the widowed Curie and her daughters, spending most of her time in a little wooden cart (like a trundle bed, I imagine). Much of the book consists of reflections and meditations on love and desire. There is some treatment of Marie's life with Pierre and a fairly extensive portion about her affair with Paul Langevin.

Figure 3. André Brouillet, Une leçon clinique à la Salpêtrière (1887).

This book was not to my taste in many respects. It blurred fact and fiction to such a great extent such that it is difficult to know what was actual and what imaginary. The centrality of some sexual situations, including the scandalous relationship of Curie and Langevin, was not my cup of tea. And I found the highly non-linear style with elements of stream of consciousness rather tedious. Here is an example, somewhat atypical in that it contains some scientific terms, but typical in its open-ended questioning about the nature of love:

"What is the chemical formula for desire?

"And why isn't there any standard meter for love? Why does love constantly change, quite unlike the standard meter, that ten-millionth of the earth's meridian quadrant? Why is there no atomic weight for desire, confirmed, awarded with a prize, for everyone, for all time, forever?"

Imaginative Historical Fiction

The last few books have plots that are not primarily biographical.

Renewable Fuel from the Desert?

The title character of *The Sun Chemist* (*9*) is Chaim Weizmann, and over the course of this 1976 novel, quite a bit of Weizmann's life story is told. But that story is not, at least ostensibly, the plot of the book, which is set in the 1970s (20 years after Weizman's death). Rather the foreground plot is a suspense thriller as the protagonist attempts to uncover a practical way to produce a biofuel, and petroleum interests attempt to suppress it.

The protagonist is Igor Druyanov, a fictitious historian and editor of a couple of volumes of Weizmann's correspondence; all of the events of the book are described from Druyanov's perspective. One of Weizmann's letters offers a tantalizing clue that he and one or more of his collaborators may have found a way to make petrol from sweet potatoes. This would be quite a boon for Israel and the world in the aftermath of the 1973 Yom Kippur War and OPEC oil embargo. Druyanov is an unlikely hero, alternately tracking down clues to the process for making the fuel in old letters and documents, attempting to keep the process (and himself) safe from those who seek to suppress it, and enjoying occasional amorous adventures.

Along the way, much of Weizmann's truly extraordinary life as a poor Russian Jew, fermentation chemist, Zionist leader, and first president of Israel is related. Druyanov thinks of Weizmann, the subject of his historical work, affectionately but not uncritically. He often refers to him by a name, Chaimchik, used by his wife Vera in correspondence. Much of the book is set at the Weizmann Institute in Rehovot, Israel, particularly at the Weizmanns' last residence.

The novel's author, Lionel Davidson, devises multiple opportunities for Druyanov to talk or think about Weizmann, prompted by his letters or house. The foreground plot of *The Sun Chemist* is a McGuffin. The *plot* is not biographical, but the book is undoubtedly about Weizmann.

Isaac Newton: Mad Alchemist and Currency Cop

The next examples come from a trilogy of adventure novels collectively called the Baroque Cycle, by an author better known for cyberpunk than for period fiction. Readers of the Baroque Cycle familiar with Neal Stephenson's other novels will recognize his manic style of storytelling and the attractive mix of bravado and intelligence typical of his invented characters. Such readers will by no means get an idea of what life was like in, say, London during the reign of William and Mary, but they will meet many of the actual inhabitants of that time doing some of the things they really did.

Robert Boyle and several other early members of the Royal Society put in cameo appearances of this sort in the first volume, *Quicksilver* (*32*). Alchemy is an important theme—not surprisingly given the title. Isaac Newton's role in *Quicksilver* is more than a cameo; his alchemical activities have a fairly prominent supporting role. Here Newton is depicted as a hybrid between his actual eccentric and prickly personality and that of a stereotypical mad scientist.

In the third volume, *The System of the World* (*33*), Newton is still more prominent—as he ought to be, in a book that bears the same title as the final volume of his *Principia*. Here he is Warden of the Mint (a post he actually held), and he pursues the fictitious protagonist, Jack Shaftoe, for "coining" (counterfeiting). In this volume, Newton's character again displays some of his actual traits, this time combined with those of a hanging judge. Shaftoe is actually guilty of coining, but that does not necessarily mean that the trial of the pyx (a combination legal ritual and analytical chemistry procedure) will show him to be guilty.

The Winner of the First Retro-Nobel Prize

The final book considered here is on the Lab Lit list, one that falls into Djerassi's science-in-fiction category (or rather his closely related science-in-theatre), and another one in which Priestley is a main character: the play *Oxygen* (*34*), written by Djerassi and Roald Hoffmann. The play alternates between the present (2001) and the past (1777). In the present a committee of fictitious contemporary chemists deliberates over the award of the first retro-Nobel Prize in chemistry, assisted by a fictitious historian of science. The committee comes to a quick consensus that the discovery to be recognized is that of oxygen, but they split over who deserves credit for it. The candidates are Priestley, Carl Wilhelm Scheele, and Antoine Lavoisier. In the fictitious past, the real contenders put their cases for recognition before the King of Sweden. To put their claims in a nutshell, Scheele made it first, Priestley published first, and Lavoisier explained it best. The spouses of the scientists also appear in the play. Indeed, Madame Lavoisier (born Marie Paulze) is its most interesting character. She is much more active and self-assured than Mrs. Priestley or Fru Pohl (who was not yet Scheele's wife), and she holds her own among the men as well as the women. A key plot point turns on a letter from Scheele that Madame Lavoisier hid from her husband. (The letter was real and Madame Lavoisier *did* manage her husband's correspondence, but her hiding the letter was an invention of the authors.) The 1777 action is entirely imaginary, albeit among characters based on real people often talking about real events.

Conclusion

Neither the unsystematic overview of fictional characters in chemistry which opens this chapter nor the more detailed summary of historical chemists in fiction suggests any conclusions based on overarching similarities. Indeed, the examples are so different in tone, theme, and aim that it would be foolish to look for many common features. As already noted, the books and stories that feature fictional chemists can be escapist or serious, using chemistry as a plot device, an incidental attribute of a character, or the focus of an attempt to realistically portray life in science.

It is a rare work of fiction that has an historical chemist as a major character. These books share one drawback with historical fiction of all sorts and with movies based on true stories: leaving the reader confused over what is fact and what was imagined. Some chemists were part of very dramatic events, ones that make for good story-telling; perhaps the truth of those events is at least as interesting as fiction.

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Chapter 9

Yegor Yegorovich Vagner (1849−1903): A "Wondrously Sharpwitted" Chemist

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Yegor Yegorovich Vagner (Егор Егорович Вагнер, Georg Wagner) was both a genius and a character. Sent to boarding school in western Russia, he ran away at age 16, covering 1,000 miles back to his home alone. After qualifying to enter the university, he began studying law, only to start afresh when he discovered chemistry. As a student, he was an active participant in the local amateur theater; years later, his lectures were a great experience for the students. As a chemist, he developed a useful alcohol synthesis with alkylzinc reagents, turned potassium permanganate into a useful reagent for the site-specific oxidation of alkenes, first proposed the rearrangements that occurred during certain reactions of bicyclic monoterpenes, and proposed the first correct structures of many of the monocyclic and bicyclic monoterpenes...and through it all, he found time to enjoy himself!

Introduction

What constitutes a "character in Chemistry"? The answer to this question is certainly going to depend on who is answering it, since each person has a different concept of what is needed to be a "character." For this chapter, I suggest that there are four major criteria against which individuals should be judged:

1) a "character" is usually a non-conformist in some way;
2) a "character" is often flamboyant, especially when compared with his/her peers;

3) a “character” often comes from a fairly atypical family situation; and
4) a “character” usually performs far outside the norms for her/his peers in the same discipline.

Russia in the nineteenth century produced its share of both characters in chemistry, and brilliant chemists. The irascible Vladimir Vasil’evich Markovnikov (*1*) (Владимир Васильевич Марковников, 1838−1904), who left one position after quarreling with the administration, and who was summarily dismissed from another following the machinations of his enemies, certainly qualifies; so does Dmitrii Ivanovich Mendeleev (Дмитрий Иванович Менделеев, 1834−1907), the father of the periodic table, about whom stories abound. Nikolai Nikolaevich Zinin (Николай Николаевич Зинин, 1812−1880), whose discovery of the reduction of nitrobenzene became the cornerstone for the dye industry, was a baritone who would join his students in caroling every Christmas, and who greeted them in the laboratory with bear-hugs. Markovnikov’s contemporary, rival, and *bête noir*, Aleksandr Mikhailovich Zaitsev (Александр Михайлович Зайцев, 1841−1910) flouted the traditions of Russian academia by leaving Russia before he had received his degree of *kandudat*, and compounded this by writing a dissertation extolling the theories of Kolbe—structural theory’s most ardent opponent—that he submitted to Butlerov—structural theory’s most ardent proponent; and yet he still had the political skills to be able to return to a professorship in Russia that he held for four decades. Aleksandr Porfir’evich Borodin (Александр Порфирьевич Бородин, 1833−1887), the chemist who made beautiful music, and the composer who made beautiful chemistry; Aleksei Yevgen’evich Chichibabin (Алексей Евгеньевич чичибабин, 1871−1945), the Markovnikov student whose battles against the system included having several mentors before graduating with his *Magistr Khimii* degree (Zelinskii referred to him disparagingly as a “self-made man” during the oral defense of the dissertation), and who wrote a textbook of organic chemistry a few pages at a time, exchanging them for ration vouchers in the aftermath of the Russian revolution; Nikolai Matveevich Kizhner (Николай Матвеевич Кижнер, 1867−1935), who was nearly crippled by disease, and who spent a year in exile from Tomsk (a city already in Siberia!) for his anti-tsarist political activities—all these, too, were characters in chemistry. But in this chapter, we will focus on one of the most brilliant minds to come out of Russia in the nineteenth century; this chapter is dedicated to the life and work of Yegor Yegorovich Vagner (Егор Егорович Вагнер), known in the west as Georg Wagner.

Vagner’s Family Origins

East Prussia: Family Origins

Vagner’s family (Figure 1) originated in East Prussia, where his great-grandfather was a pastor (*2–7*). During the eighteenth century, there had been a policy of actively encouraging immigration to Russia, instituted by Catherine the Great, and continued by her successors (although with gradually reduced financial enticements). One of the more successful migrations was the migration of Germans to the Volga region of Russia (*8*), where the Tsars hoped that the influx of Christian migrants would help to slow Islamic expansion. The rapidity of this migration alarmed Joseph II, Emperor of Prussia, sufficiently that he effectively forbade migration to Russia by the end of the eighteenth century. However, the stage had been set.

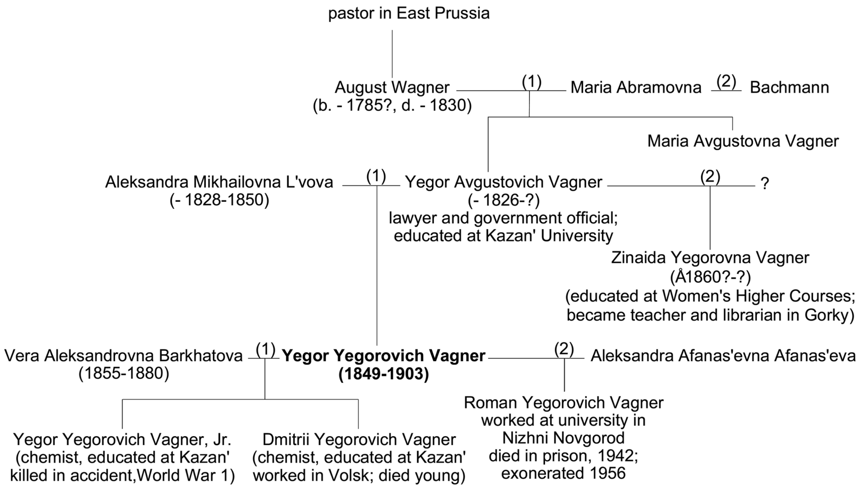


Figure 1. Vagner's family tree.

August Wagner

Early in the nineteenth century, August Wagner, who had completed his training as a pharmacist in East Prussia, informed his father that he was going to migrate to Russia to seek his fortune, and over the vehement protests of his father, he left for Kazan, on the Volga River, some 600 miles east of Moscow. Here he set up his own pharmacy, and rapidly set about acclimatizing himself to his new country; he quickly became proficient in Russian. Thanks to his skills as a pharmacist and his charming personality, he was soon a rich man. August married a local girl from the German community, and had two children, a son, Yegor (Егор Августович), and a daughter, Maria (Мария Августовна). Although the marriage was a happy one, it was also short—August Wagner died suddenly in the prime of his life. It seems clear that Wagner was committed to his new country, since both his son and grandson chose to use the name *Yegor* (Егор), rather than the alternative form, *Georgii* (Георгий), to emphasize the fact that they were Russian, and not German.

Wagner's widow remarried, choosing for her second husband another pharmacist of German origin, named Bachmann. He became an important figure in the life of the children, who were fortunate that he was of a kindly disposition towards them. As Yegor Avgustovich grew, he was sent first to the Gymnasium, where he excelled as a student, and then to Kazan University, where he graduated in Law. On his graduation, Vagner entered public service.

Shortly after graduating, Vagner married Aleksandra Mikhailovna L’vova (Александра Михайловна Львова), the daughter of the Director of the second Kazan Gymnasium, and a member of the local nobility. The L’vov family was well known for their artistic bent—the playwright Nikolai Mikhailovich L’vov (Николай Михайлович Львов, 1821−1872) was Vagner’s uncle—and Aleksandra especially loved music and the theater arts; this passion she passed on to her son. She fell pregnant shortly after her marriage, and at the same time she fell ill. Since Yegor Avgustovich’s job required constant travel, Aleksandra Mikhailovna returned to Kazan, where she lived with her in-laws. It was here that her son, Yegor Yegorovich Vagner (Figure 2), was born on November 17, 1849 (old style, November 29, 1849 new style). Less than a year later, Aleksandra Mikhailovna was dead from tuberculosis, a disease that claimed a number of members of the L’vov family.

Figure 2. Yegor Yegorovich Vagner (Егор Егорович Вагнер, 1849−1903) as a student at Kazan University. Source: Downloaded from the official web site of the Museum of the Kazan University School of Chemistry. http://old.kpfu.ru/museums/chmku/eng/s5.php (accessed September 2012).

His mother’s death, and his father’s effectively nomadic job meant that the task of raising young Yegorushka, as he was affectionately called, fell to his grandparents, the Bachmanns. On her deathbed, Aleksandra had extracted a promise from her mother-in-law to take her son into her home while his father was on the move, and the old woman kept her oath.

After his second marriage, Vagner’s father received a permanent posting to the Excise Office in Kazan, which meant that he could finally settle down in one place. At this juncture, he talked with his parents, who begged him to allow the child to stay with them, since they had raised him from infancy. Yegor Avgustovich was not a fool, and realized how much difficulty the transition to his father’s home would entail for the boy, so he left him with his grandparents. He did, however, frequently visit his son, and when he did so, he showered him with gifts.

Vagner's Early Schooling

After Mr. Bachmann's death, Vagner's grandmother was no longer able to educate her grandson. A family council was convened, and it was decided that Yegorushka should be sent to boarding school. The school chosen, the Leffler boarding school, was near the city of Wenden, in Livonia (modern Cēsis, in Latvia); it had a reputation as a first-rate academic institution. Vagner did not stay until graduation; he ran away from school and returned home to Kazan at age sixteen. Even so, he still managed to perform so well in his studies that he was consistently ranked near the top of his class, and his teachers all thought highly of him. Following his return home, a letter arrived from the boarding school that said that despite his "excessive vivacity," he was a conscientious student, and would make a good judge. From 1867 on, Vagner was intensively home-schooled. He applied himself diligently to his studies in preparation for entry into Kazan University (Figure 3), and by passing the required entrance examinations—in Mathematics, Physics, History, Geography, Russian literature, Latin, French and German—he was permitted to enter the university. His father's influence almost certainly played a part in his choice of program, but in the 1860s, Russian politics and law were in a state of flux as the reforms of Tsar Aleksandr II were enacted, and this made law an attractive career choice for Vagner, who entered the Juridicial Faculty as a student in judicial science.

Figure 3. Kazan Imperial University ca. 1832. Source: Downloaded from http://commons.wikimedia.org/wiki/File:Kazan_University,_1832.jpg (accessed September 2012).

Vagner, The University Student

Kazan

His first two years at the university were easy for a student as brilliant as Vagner, and his classes in the Juridicial Faculty meant that he had plenty of time for extracurricular activities, including the theater (most students at Kazan at this time were theater aficionados). During his third year, some of Vagner's friends persuaded him to attend some of the lectures given in the natural science (i.e. chemistry) division of the Physics−Mathematics Faculty. This was an epiphany, as he quickly found himself embracing science: in August, 1869, he petitioned the rector of the university to be permitted to transfer to the Physics−Mathematics faculty. The permission was granted, but by the rules of the University, *third-year* law student Vagner became *first-year* science student Vagner. The change in career path was accompanied by a change in attitude: Vagner became a student passionate about his studies.

In 1869, Kazan boasted one of the strongest schools of chemistry in Russia. The leading individuals in establishing the Kazan School of Chemistry are shown in Figure 4. The school had been founded by Zinin and Karl Karlovich Klaus (Карл Карлович Клаус, 1796−1864), and consolidated by their student and successor, Aleksandr Mikhailovich Butlerov (Александр Михайлович Бутлеров, 1828−1886). In 1869, chemistry was taught by bright, young professors, amongst whom were Butlerov's students, Zaitsev and Markovnikov. Although Markovnikov soon departed for Odessa, Zaitsev was to spend the next four decades at Kazan as Professor of Organic Chemistry, and it was Zaitsev who became the primary influence over young Vagner.

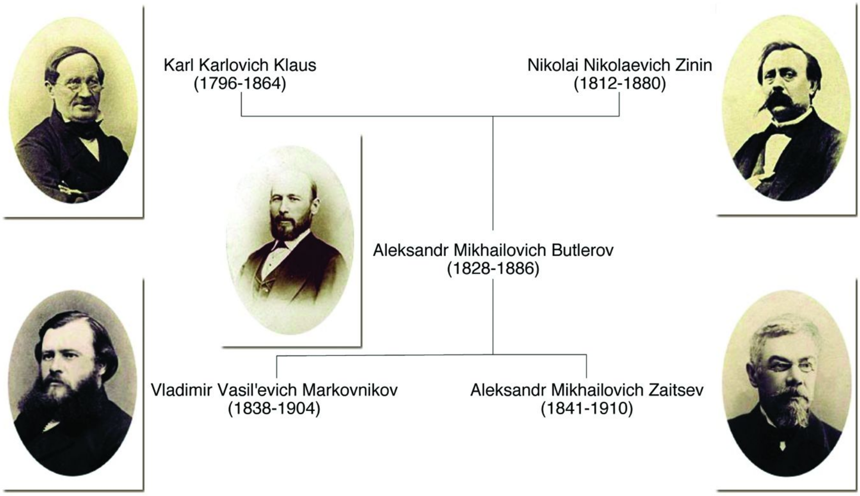


Figure 4. Leading figures in the development of the Kazan School of Chemistry. Source: All portraits in this figure are taken from the official web site of the Museum of the Kazan University School of Chemistry. http://old.kpfu.ru/museums/chmku/eng/index.htm (accessed September 2012).

In 1863, Butlerov had reported the synthesis of *tert*-butyl alcohol by the reaction between acetyl chloride and dimethylzinc (*9–12*), thus beginning over three decades of organozinc chemistry at Kazan University (*13*); two years later, Frankland and Duppa reported the synthesis of α-hydroxyesters from the reaction between an α-ketoester and an organozinc reagent (*14*, *15*).

By his third year as a science student, Vagner was working in Zaitsev's laboratory, studying the reactions of dialkylzinc and alkylzinc halide reagents with formate esters. At the time that Vagner entered his laboratory, the primary focus of Zaitsev's work was the synthesis of tertiary alcohols by the reaction between acid chlorides or ketones, and dialkylzinc or alkylzinc iodide reagents (*16–23*), extending the work of his mentor, Butlerov. So, extending the reaction further, to look at aldehydes and formate esters, was logical. Using this reaction, Vagner was able to synthesize symmetrical secondary alcohols; this reaction was the first general method for preparing secondary alcohols (*24–26*). Early methods for the synthesis of alcohols based on organozinc reagents are gathered in Figure 5.

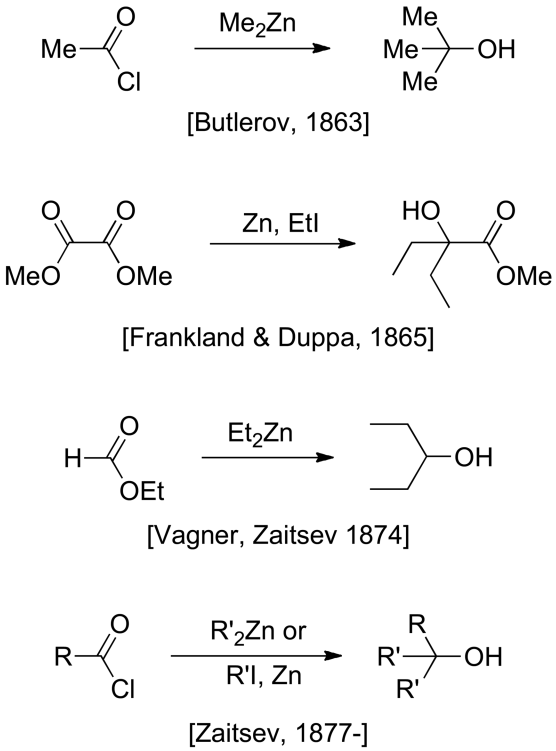
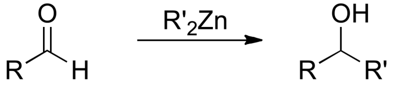


Figure 5. Early methods for the synthesis of alcohols using organozinc reagents.

Vagner graduated with high grades in 1874, and was consequently invited to submit a dissertation for the degree of *kandidat* by the Physics−Mathematics Faculty. This he did in the fall of 1874 (*27*); the dissertation was examined by the docent, Grigorii Nikolaevich Glinskii (Григорий Николаевич Глинский, 1842−1884), and on his favorable report, Vagner received the degree by unanimous vote of the faculty. He continued working in Zaitsev's laboratory, and at Zaitsev's request, Kazan University awarded him one of the stipends intended for students preparing for the professoriate. Zaitsev knew that he had an extraordinary student on his hands, and that the opportunity to study with the most eminent chemists in Russia would be important in his development. Since the majority of those chemists were in St. Petersburg at that time, Zaitsev requested that Vagner be awarded a *komandirovka* (study abroad) to study there. On a 29−6 vote, the University awarded him the *komandirovka*. Zaitsev's actions here, given that he knew that his actions would lose him the services of a highly talented student, speak highly of his concern for his student.

St. Petersburg

In 1876, Vagner moved from Kazan to St. Petersburg, with a letter of introduction to Butlerov from Zaitsev. His first research work at St. Petersburg involved the continuation of the organozinc syntheses he had begun at Kazan under Zaitsev. In St. Petersburg, he extended the synthesis of secondary alcohops from formate esters and dialkylzinc reagents to the preparation of unsymmetrical secondary alcohols from aldehydes and organozinc reagents (Figure 6). Over the next six years or so, he undertook a systematic study of this reaction, which he published in a series of papers in Russian and German (*28–31*), including a 70-page paper in the *Zhurnal Russkogo Fiziko-Khimicheskogo Obshchestva* (*31*). This was the first general preparation of this class of compounds.



R=H, Me, Et, Pr, *i*-Pr, *n*-Bu, *n*-C_5H_{11}, *n*-C_6H_{13}, $H_2C{=}CH$, Ph, *o*-$MeOC_6H_4$
R'=Et, Me, *n*-Bu, *n*-C_5H_{11}

[Vagner, 1876-1888]

Figure 6. Vagner's synthesis of unsymmetrical secondary alcohols.

At the same time that he entered Butlerov's research laboratory, Vagner became the Laboratory Assistant in Analytical Chemistry under Nikolai Aleksandrovich Menshutkin (Николай Александрович Меншуткин, 1842−1907). Menshutkin (Figure 7) was a pioneer in the field of physical organic chemistry (*32*, *33*). His name has come down to modern times in the form of the Menshutkin reaction (*33*), in which a quaternary ammonium salt is formed by nucleophilic substitution of a tertiary amine with an alkyl halide. It was this reaction that led Menshutkin to propose that the solvent plays an important part in determining the course and the rate of a chemical reaction (*34–37*) three decades before the seminal studies of Hughes and Ingold (*38*).

Figure 7. Nikolai Aleksandrovich Menshutkin (Николай Александрович Меншуткин, 1842−1907). Source: Photograph published in Witt, O.N. J. Chem. Soc., Trans. ***1911****, 99,1646−1668. Downloaded from http://en.wikipedia.org/wiki/File:Menshutkin.jpg (accessed September 2012).*

During his time in Menshutkin's laboratory, Vagner became friends with the Laboratory Assistant in analytical chemistry, Aleksei Lavrent'evich Potylitsyn (Алексей Лаврентьевич Потылицын, 1845−1905); their friendship grew as they directed the work of students in the quantitative analysis laboratory. In 1881, Potylitsyn was appointed Professor at the Novo-Aleksandriya Institute of Agriculture and Forestry (Figure 8), and in 1883, he became Professor at Warsaw Imperial University, a position he held for the next twelve years. In 1895, he returned to Novo-Aleksandriya as Director of the Institute, a post he occupied until 1900.

Figure 8. The Novo-Aleksandriya Institute of Agriculture and Forestry in the Pulavski Palace near Warsaw. Source: Photo 130 downloaded from http://www.ksu.ru/museums/chmku/eng/fonds6.php (accessed December 2012).

In Characters in Chemistry: A Celebration of the Humanity of Chemistry; Patterson, G., et al.; ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

Vagner's First Independent Post: Novo-Aleksandriya Institute of Agriculture and Forestry

Within the first year of his appointment as Professor at the Novo-Aleksandriya Institute of Agriculture and Forestry, near Warsaw, Polylitsyn approached the Director of the Institute with the suggestion that Vagner be appointed to the position of Docent in forestry and agricultural technology at the Institute. Since such a transfer required approval by the Rector of the candidate's current institution, the Director of the Institute approached the Rector of St. Petersburg University. Thanks to Menshutkin's assessment that, "no obstacles to the transfer of Egor Egorovich Vagner exist," Vagner moved to Novo-Aleksandriya, and took up his position in January, 1882.

At Novo-Aleksandriya, Vagner began his investigations into oxidation reactions with chromates and permanganate. Another Kazan product, Aleksandr Nikiforovich Popov (Александр Никифорович Попов, *ca.* 1840−1881), had occupied the Chair of Chemistry at Warsaw Imperial University since 1869, and had studied the oxidation of ketones by chromic acid (*39–43*). On the basis of his studies, he had proposed a rule (Figure 9) that stated that when a ketone is oxidized, two acids are formed, with preferential oxidation of the bond between the carbonyl and the adjacent alkyl group decreasing in the order:

$$Ph \approx R_3C < Me < RCH_2 < R_2CH < PhCH_2.$$

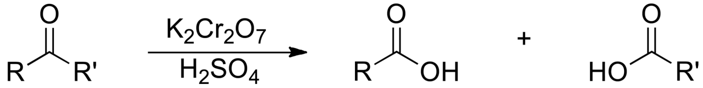


Figure 9. Popov's Rule for the oxidation of ketones.

Vagner re-visited this reaction, and found that not two, but four acids were produced from the oxidation of unsymmetrical ketones (*44*): for example, ethyl hexyl ketone provided acetic acid, propionic acid, valeric acid, and caproic acid (Figure 10).

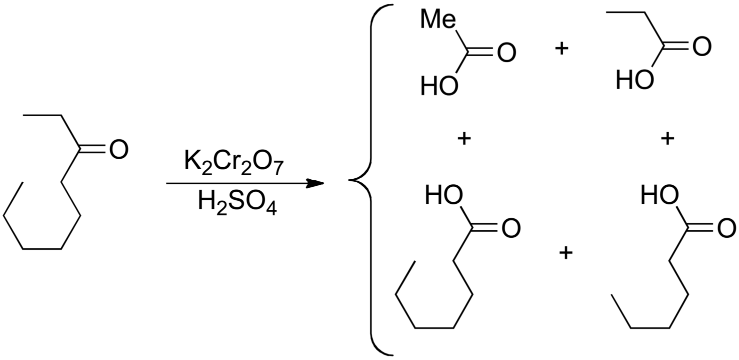
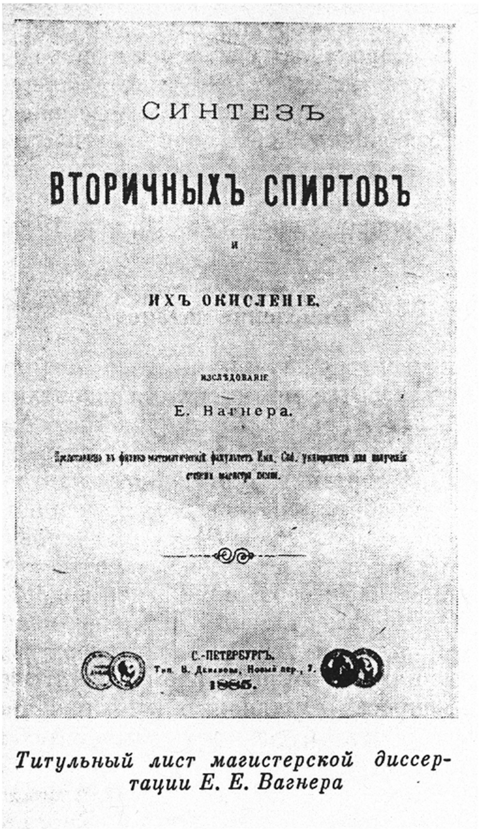


Figure 10. Vagner's study of ketone oxidation by chromic acid.

Combined with his earlier work, in which he had developed the first general synthesis of unsymmetrical secondary alcohols, this study provided the basis for his *Magistr Khimii* (M. Khim.) dissertation, which he submitted to St. Petersburg University in 1885 (*45*). This dissertation (Figure 11) was a monumental work, and his biographers are almost unanimous in their assertions that it contained enough work for two such dissertations.

Warsaw Imperial University

In 1886, Vagner, who now held the degree of *M. Khim.* that was required to occupy a professorship, accepted the invitation of Warsaw Imperial University to take the chair of organic chemistry. Although the institution was more prestigious than the Novo-Aleksandriya Institute, its laboratory facilities were almost non-existent, and there was no organic chemistry laboratory, so Vagner had to work in a small room behind the lecture hall. His enthusiasm continued unabated, however, and soon he was producing the work on the oxidation of alkenes with dilute basic permanganate that would be pivotal to his work on the terpenes.



СИНТЕЗЪ

ВТОРИЧНЫХЪ СПИРТОВЪ

и

ИХЪ ОКИСЛЕНІЕ.

изслѣдованіе

Е. Вагнера.

Представлено въ физико-математическій факультетъ Имп. Спб. университета для полученія
степени магистра химіи.

С.-ПЕТЕРБУРГЪ.
Тип. В. Демакова, Новый пер., 7.
1885.

Титульный лист магистерской диссертации Е. Е. Вагнера

Figure 11. The title page of Vagner's M. Khim. dissertation. Source: Ref. (3).

The first forays into the oxidation of unsaturated organic compounds with potassium permanganate was not Vagner's, but Sevast'yan Moiseevich Tanatar (Севастьян Мойсеевич Танатар, 1849−1917), who oxidized maleic and fumaric acids with alkaline potassium permanganate (*46*, *47*) to obtain what are now known as *meso*-tartaric acid, and *dl*-tartaric acid. In 1885, Vagner's mentor, Zaitsev, reported the oxidation of oleic acid and its geometric isomer by alkaline permanganate (*48*, *49*). In both these earlier studies, the role of the base was probably viewed as being to facilitate the reaction by converting the acids into their much more water-soluble potassium salts.

Vagner's great intuitive leap was to recognize that water-solubility was not necessarily vital to the oxidation of alkenes by potassium permanganate, and his series of careful researches (*50–52*) established several important features of this reaction: 1) the concentration of the oxidizing agent must be kept below 4%; 2) the presence of base was essential to prevent over-oxidation; and 3) the double bond did not migrate during this reaction, *so the reaction could actually be used to locate the position of double bonds within an unsaturated organic compound.* This is nicely illustrated by the example of oxidation of the dehydration product of *tert*-amyl alcohol, which had been assumed to give 2-methyl-2-butene in keeping with Zaitsev's findings on eliminations (*53*). When this olefin was oxidized with 4% aqueous potassium permanganate in the presence of sodium hydroxide, Vagner reported that two fractions were obtained after distillation of the reaction mixture; the major isomer he ascribed to "trimethylethylene glycol", or 2-methylbutane-2,3-diol, and the other (higher boiling) may be deduced to be 2-methylbutane-1,2-diol (Figure 12).

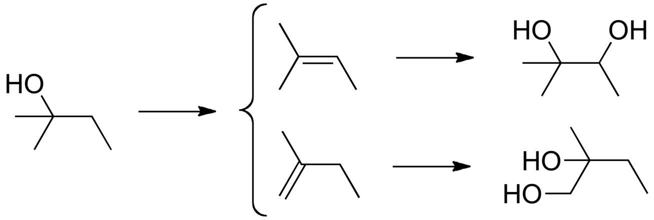
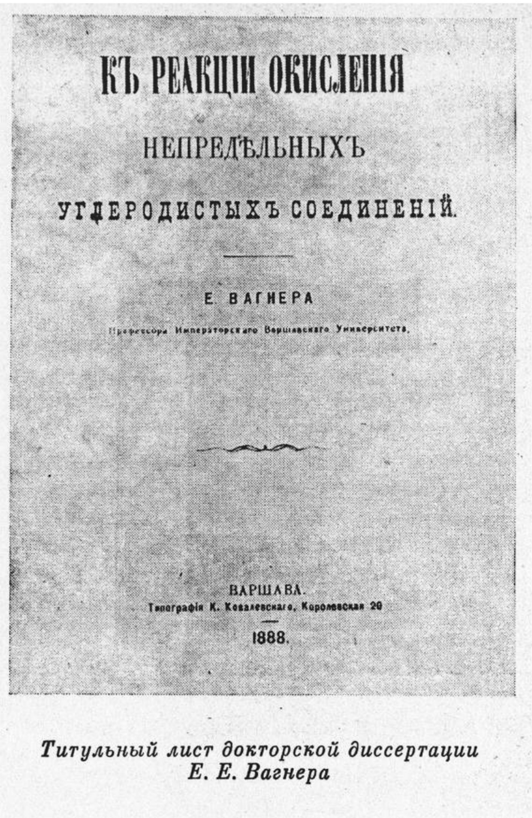


Figure 12. Vagner's demonstration that oxidation of alkenes with dilute basic potassium permanganate does not result in double bond migrantion.

This work became the subject of his Dr. Khim. dissertation (Figure 13), which he submitted to Warsaw University in 1888 (*54*). This feature of the reaction—that it allowed the precise location of double bonds to be determined without the complications of isomerization—became a cornerstone of his methods for determining the structures of the terpenes in the last decade and a half of his life.

Warsaw Technological Institute and Terpenes

The final stages of Vagner's career were spent at Warsaw Technological Institute, as Professor of Organic Chemistry, and Dean of the Chemistry School. He was invited to the faculty of the Institute in 1889, the year after his Dr. Khim., and he remained there for the reaminder of his career. For his first three years at the Institute, he held concurrent positions as Professor of Chemistry at Warsaw Imperial University, and as Professor of Organic Chemistry at the Institute. Although this practice was common at the time as a means of improving the (often inadequate) salary of the professor, Vagner decided that he could properly run only one laboratory at a time. Since the laboratories at the Technological Institute were more modern and better equipped, he chose the Institute.



КЪ РЕАКЦІИ ОКИСЛЕНІЯ
НЕПРЕДѢЛЬНЫХЪ
УГЛЕРОДИСТЫХЪ СОЕДИНЕНІЙ.

Е. ВАГНЕРА
Профессора Императорскаго Варшавскаго Университета.

ВАРШАВА.
Типографія К. Ковалевскаго, Королевская 20

1888.

Титульный лист докторской диссертации
Е. Е. Вагнера

Figure 13. Title page of Vagner's Dr. Khim. dissertation. Source: Ref. (3).

It was at the Technological Institute that Vagner made his seminal discoveries concerning the cyclic and bicyclic monoterpenes. In the last decades of the nineteenth century, the structures of the terpenes had become one of the all-consuming questions of organic chemistry. Many of the major organic chemists in the world began to focus their attention on the problem: Friedsrich August Kekulé (1829−1896), [Johann Friedrich Wilhelm] Adolf von Baeyer (1835-1917), the winner of the 1905 Nobel Prize in Chemistry, Otto Wallach (1847−1931), the 1910 Nobel laureate in Chemistry, [Konrad] Julius Bredt (1855−1937), [Johann Karl Wilhelm] Ferdinand Tiemann (1849−1899), Henry Edward Armstrong (1848−1937), and William Augustus Tilden (1842−1926) all entered the fray, and each proposed structures for the various terpenes. The problem was not trivial, since most of the terpenes in nature exist as mixtures which had to be painstakingly separated by fractional distillation. It is not for nothing that Wallach was awarded the Nobel Prize in 1910!

Sementsov's account of Vagner's terpene research makes fascinating reading (*6*), but here we will restrict our discussion to what may have been the thorniest of all the monoterpenes: the structure of pinene. As one of the most abundant of the monoterpenes, α-pinene was plentiful, and was among the first to be obtained in pure state, and among the first to be examined. During the last three decades of the nineteenth century, no fewer than nine chemists had proposed incorrect structures (Figure 14) for this hydrocarbon (actually, the figure is ten, if one counts Vagner's incorrect 1891 structure).

The structures proposed for this fascinating hydrocarbon cover the full range from acyclic structures, proposed (*55*) by Flavian Mikhailovich Flavitskii (Флавиан Михайлович Флавицкий, 1848−1917) and by Tilden (*56*) in 1878, to monocyclic structures, based on the menthane skeleton, to bicyclic structures based on the menthane skeleton, as well as the bornane and pinane skeletons. The first structure formally proposed for pinene was Oppenheim's monocyclic structure (*57*), which actually corresponds to α-phellandrene. A year later, Kekulé modified the Oppenheim structure, and proposed the non-conjugated isomer of the same hydrocarbon (*58*). All the other proposed structures were bicyclic. The isomeric structures proposed (*59*) by Zaitsev's student, Innokentii Ivanovich Kanonnikov (Иннокентий Иванович Канонников, 1854−1902) and by Wallach (*60*) were still based on the menthane skeleton, by simply bridging the ring. The first relatively radical bicyclic structure for pinene was that of Armstrong (*61*), who proposed a bicyclo[4.2.0]oct-7-ene derivative—not based on the menthane skeleton—containing a cyclobutene ring (note how, when they are drawn the modern way, the Kanonnikov and Wallach structures each contain a cyclobutene). In 1893, Bredt (*62*) proposed a structure based on the bornane skeleton that, interestingly, actually violates what we now call Bredt's rule (*63*), proposed some three decades later by the same author! Another anti-Bredt structure for pinene—this time based on the correct carbon skeleton—was proposed by Tiemann and Semler, in 1895 (*64*).

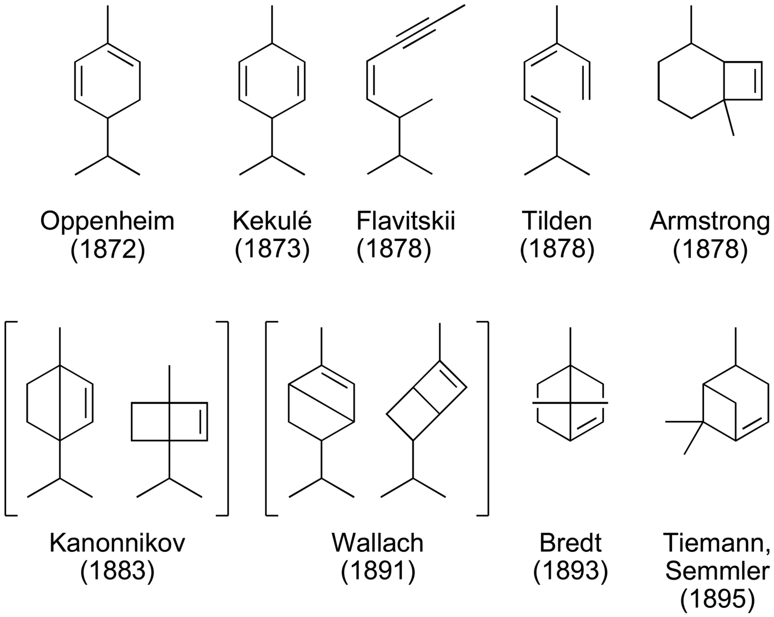


Figure 14. Structures proposed for α-pinene.

Vagner's Contributions on Pinene

Vagner's foray into terpene chemistry was successful because he was a voracious reader, and had an encyclopedic knowledge of his subject matter, and because he was able to assess and use the results of his contemporaries without being swayed by their deductions. Like those contemporaries, he was not immediately successful (Figure 15). The first structure that he published for pinene was yet another bridged menthane structure that was the anti-Bredt isomer of the Wallach structure (*65*). By 1894, however, he had concluded that pinene could not carry an isopropyl group (*66*), thus invalidating his own earlier structure, as well as two-thirds of the rest.

In 1896, Vagner's paper followed that of Tiemann, who had proposed the correct bridged-ring structure for the pinane skeleton, but had located the double bond in the wrong place. In this paper, Vagner proposed three structures based on the pinane carbon skeleton. The first of these structures (pinene-I) is the accepted modern structure of α-pinene; the second and third are other anti-Bredt isomers of Tiemann's structure.

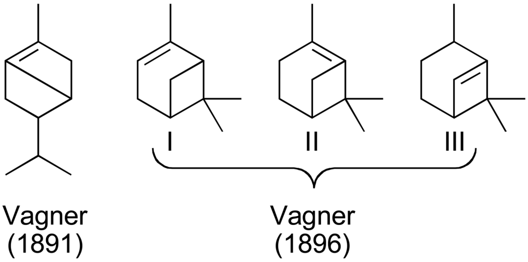


Figure 15. Vagner's proposed structures for pinene.

Vagner's approach to this problem (summarized in Figure 16) was typical: Knowing that his permanganate oxidation occurred without concomitant isomerization of the double bond, he initially oxidized the alkene with dilute, alkaline permanganate to pinene glycol, which he then cleaved oxidatively with permangamate. Since he did not obtain a diketone from the oxidation, it was clear that pinene-II was not the correct structure. Likewise, exhaustive oxidation of the keto-acid formed from either pinene-I and pinene-III should give different results on degradation of the carboxylic acid group (he proposed that pinene-I should give a new C_9 carboxylic acid, and pinene-III should give a diketone); a C_9-ketoacid was obtained. The upshot of these studies was that, in a series of papers beginning in 1896 (*67–71*), Vagner and his students first proposed the correct structure (pinene-I) for α-pinene, ending nearly a quarter of a century of effort across Europe.

The importance of Vagner's work on the terpenes is made absolutely clear, when one reads the assessment (*72*) by one of his competitors, Adolf von Baeyer:

> Therefore, to Herr Wagner must go the credit, in my view, of being the first to establish the correct formulas for members of the terpene and pinene groups, although much of the evidence was provided by the work of others.
>
> From the new theory, it is apparent that almost all of my proposed formulas are wrong, with the exception of the terpinolene group. Furthermore, as G. Wagner has already noted, my claim that the activity of limonene does not agree with van't Hoff's law, is null and void.

[—As an aside, when is the last time you have heard a Nobel laureate in chemistry admit error in such unequivocal and forthright terms?]

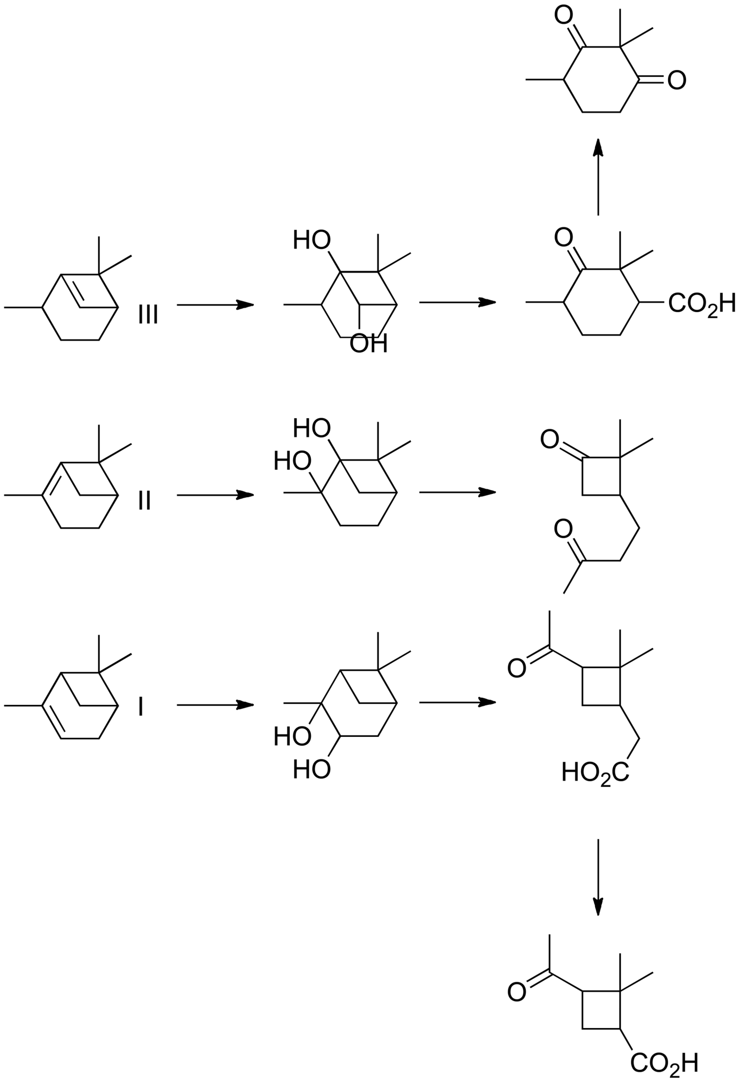


Figure 16. Vagner's deduction of the correct structure of pinene.

The Wagner−Meerwein Rearrangement (*73*)

One of the major problems associated with the study of the terpenes was the fact that on treatment with acid, these compounds often produced a dizzying array of products. Vagner's oxidation methods, being alkaline, did not lead to such a wide range of products, and so allowed him to deduce the structures of most of the monoterpenes by simple application of permanganate oxidation.

Today, we know that the reason for the wide range of products formed in reactions of terpene hydrocarbons under acidic conditions is due to the formation and rearrangement of carbocations. Vagner and his student, Vaclav Brykner

(Вацлав Брыкнер), who later reported the formation and structure elucidation of bornylene (*74*), reported the rearrangement of the pinane skeleton to the bornane skeleton in their 1899 paper describing the conversion of pinene to bornyl chloride, and the conversion of camphene to isobornyl chloride as part of their establishment of the structure of camphene (*75*, *76*) (Figure 17).

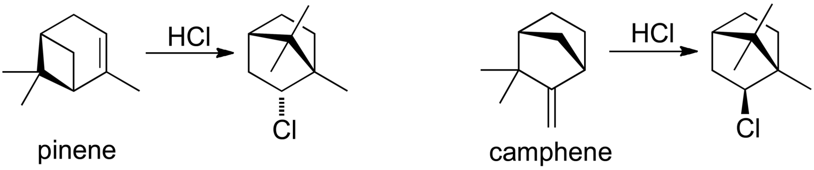


Figure 17. The Wagner−Meerwein rearrangements observed by Vagner.

This was the first suggestion that the carbon skeleton of an organic compound other than a pinacol could rearrange during a reaction, but it was Meerwein's work (*77*), where he postulated the carbocation intermediates, that allowed this puzzle to finally be solved. In that seminal paper, Meerwein described Vagner's contributions in terms even more glowing than those used by von Baeyer two decades earlier:

> With wondrous sharpwittedness [bewunderswürdigen Scharfblick], by 1899, in the same paper where, for the first time, he put forward the now generally accepted formula for camphene, G. Wagner had already drawn the parallel between the formation of camphene from borneol and the rearrangement in the conversion of pinacolone alcohol into tetramethylethylene.

Unfortunately, Vagner's untimely death—from complications of surgery to treat colorectal cancer, rather than from heart disease (Vagner, a smoker, battled obesity throughout his life)—meant that he was not able to see and appreciate just how important his contributions became to modern organic chemistry.

Vagner, The Character

At the beginning of this chapter, the characteristics used to decide whether or not an individual qualifies as a "character" were introduced. In this final section, let us examine some of Vagner's traits, as revealed by his biographers, that in this author's opinion, at least, qualify him as a "Character in Chemistry".

The Child

As mentioned earlier, the strict regimentation at the Leffler Boarding School did not sit well with a free spirit such as young Vagner, who was used to considerable freedom and independence. He was frequently in trouble, and inevitably, his free spirit would out. This happened the year before he graduated. At sixteen years of age, he decided to run away from the boarding school, and return to his father's house in Kazan—a journey of over 1,000 miles! He had sufficient funds to travel by train to Nizhni Novgorod, but had to travel the last 220 miles on foot with the wagon trains. As a penniless student, he extracted food from his fellow travelers on this last leg of his journey by the promise of payment from his father once they reached Kazan. His father, ever indulgent, did so. It is interesting to note that instead of scolding the boy, his father greeted him with a benign, humorous (if a little sarcastic), "Well, brother, you're perfect, Lomonosov, just the opposite: he fled by wagon train *to* learning, and you, *from* learning!"

The Young Man

Even as a child, young Yegorushka shared his mother's passion for the theater arts. As a child, he would entertain friends and family by his expressive poetry readings from Pushkin and Lermontov. His artistic side surfaced once more while he was a student at Kazan. He became well known in the city both for his attendance at the theater, where he was not backward in critiquing the performances, and for his performances in a number of amateur productions. So strong and widespread was the involvement of many of the younger students at Kazan in the theater, that some professors teaching evening classes would try to finish early so that their students had time to get to the theater. It is reported that Vagner was a talented actor. Certainly, long after he had become an eminent chemist, he kept playbills of productions in which he had appeared as a student, and would reminisce among his students about his days on the stage.

The New Professor and Workaholic

At Warsaw, Vagner's personality showed the intensity that would characterize his entire career. Vagner was, by the modern definition, a workaholic, as is plain from the reminiscences of one of his former students, I.E. Kuvshinov:

> ... you would come to visit after lunch and see that Yegor Yegorovich was already sitting in his room and engaged. At first, newcomers would seem surprised at his intense focus, sitting in the lab, and would wonder about what was going on: "What is Yegor Yegorovich distilling, pouring, smelling?"... Then, there were often times, late at night, while you were walking in the park or returning from somewhere across the park, that you could see a light in his room, and Yegor Yegorovich himself sitting and intently watching the thermometer, or standing and adjusting something.

The upshot of this work was, as alluded to earlier, a dissertation for the degree of M. Khim. that was worthy of two such degrees.

The Teacher−Thespian

Vagner's theatrical experience showed through when he delivered lectures—his voice reached all parts of the lecture hall. And yet, for someone with his experience performing in public, Vagner was actually a little insecure when he delivered lectures to students. In his memoirs, Vagner's pupil and biographer, V. Lavrov, described his teacher as a professor and lecturer: "The lectures read by Yegor Yegorovich were fun... His sonorous and resonant voice filled the chemical auditorium. The audience listened to him so intently that, listening from the next room, it appeared that Yegor gave his lectures in an empty auditorium. At the end of most lectures, the audience expressed its love of the professor and their true pleasure by applause. As for the lectures, themselves, Yegor Ye. was probably nervous during their actual delivery for, as he himself used to say: 'When I lecture, I do look at the audience, but seldom see or discern individual familiar students.'"

The Flamboyant Professor at a Conference

A good idea of Vagner, the Professor, can be gained from the insights of students who had studied under him, or interacted with him. One such student was Vladimir Nikolaevich Ipatieff (Владимир Николаевич Ипатьев), whose pioneering work on high-pressure reactions had made him an Academician before he left Russia, who was elected to the National Academy of Science of the U.S.A., and who became a force in American industrial chemistry while at Universal Oil Products (the Ipatieff Prize awarded by the American Chemical Society was funded by him, and named in his honor). In his memoirs (*78*), Ipatieff wrote of Vagner's interactions with the students at a conference at St. Vladimir University, in Kiev, in 1898:

> Just before I left I spent most of the day and night with a group of chemists headed by Wagner himself. We dined at the Hotel Continental, the meal being supplemented by considerable drinking of our national vodka and by a most lively discussion on the papers presented at the meeting. About four o'clock in the afternoon our chemical leaders, being in a very happy frame of mind, decided to go to Trukhanov Island on the Dnieper River, where there was a restaurant and a cabaret. At the island we continued our discussion, drinking tea and cognac, which proved as popular as the vodka. After tea we saw the cabaret performance probably with more vigor than politeness. Then the celebration continued in a separate room of the restaurant with me, the only one still sober, in charge. Wagner was the life of the party and I must note that few can achieve the happy and pleasant state of mind that he could. We returned to Kiev at four o'clock in the morning and walked from the wharf to our hotel. Wagner always remembered that particular evening in Kiev, and in a letter to Favorsky later he sent me his regards, expressing gratitude for my care and dubbing me 'Colonel of Trukhanov Island'.

Clearly, having become a professor did not remove all the thespian from this gifted chemist, and one can only wonder if it was Vagner, the theatrical critic, or Vagner the performer, who emerged during the cabaret performance. It takes rather less imagination to envisage what "happy and pleasant state of mind" Vagner attained.

Conclusion

The question of what exactly constitutes making an individual a "character" is not a simple one. Certainly, a level of non-conformity helps, as does a certain flamboyance. An unusually high (or low) intellectual capacity and an unusual perceptiveness are also often hallmarks of those perceives as "characters". The subject of this chapter, Egor Egorovich Vagner (who would most likely be rather upset that he is almost universally referred today to as Georg Wagner), fulfills every one of these criteria: as a child, he ran away from boarding school rather than conform to the school rules. As a child, and then as a student at Kazan, his love of the theater, and his ability as a performer made him a popular person on campus, and his thespian qualities carried into his delivery of lectures as a professor. One might also remember his trip to Trukhanov Island with a group of students (one might also wonder how well Vagner did); surely, flamboyance personified. As an intellectual, Vagner had few peers. His perceptiveness about chemical reactivity and structure meant that he was able to deduce structures of compounds from his own results, and to make correct interpretations of the results of others where they had erred. Surely, to have solved a puzzle that had stymied two future Nobel laureates, and to elicit an admission of this fact from one of them, is something that we may never see again. As Meerwein put it, it was his "wondrous sharpwitedness" that set this character in chemistry apart from his peers.

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Chapter 10

Martian Chemists and Characters

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The five Jewish−Hungarian−American scientists—the Martians of Science—earned their fame both in research and in protecting the United States during World War II and the Cold War. They included the aerodynamicist Theodore von Kármán, physicists Leo Szilard, Eugene P. Wigner, and Edward Teller, and the mathematician John von Neumann. They all started their university careers at least in part in chemistry. They made chemical discoveries and later they also made good use of their background in chemistry. Each of the five was a special character. Politically, four were hawkish and one, Szilard, was for peaceful coexistence with the Soviet Union, but all showed liberal tendencies. This paper brings these scientists to human proximity. They are presented as characters and of their many scientific achievements, those in chemistry are sampled.

In Characters in Chemistry: A Celebration of the Humanity of Chemistry; Patterson, G., et al.;
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Introduction

We five were survivors of a shipwreck and found a lifeboat. Of course, we were eager to protect it against all dangers. Edward Teller (*1*)

Science is the art of the impossible. Leo Szilard (*2*)

There are several variants of the story about the origin of the label Martians of Science. According to one of them, a group of scientists in the Manhattan Project talked about the conspicuous presence of Hungarians in the project and someone suggested that they had come from the planet Mars, but used a disguise of speaking Hungarian; hence the Martians label.

The core of the Martians included Theodore von Kármán (1881−1963), Leo Szilard (1898−1964), Eugene P. Wigner (1902−1995), John von Neumann (1903−1957), and Edward Teller (1908−2003) (*3*). All were born in Budapest and all died as Americans (in the United States, except for von Kármán, who died during a visit to what then was West Germany). They were all born into upper-middle-class Jewish families.

When they immigrated to the United States, they did so from Germany and sometimes one can read that they were German. This impression is further strengthened by the fact that two of them have “von” in their names, which implies German nobility. However, the two “noblemen’s” fathers acquired hereditary nobility in the Austro−Hungarian Monarchy. Their names originally did not contain “von.” Their nobility could be recognized by the way Hungarian language distinguished it. However, when they left for Germany, they understood that in Germany, the Hungarian way of indicating nobility would not work, and adopted the German way of expressing it. One might say that their usage of “von” was not sanctioned officially, but nobody cared. To us it is mildly amusing that such highly intelligent men as von Kármán and von Neumann were, cared for such a distinction, but, obviously, they did.

All five grew up in assimilated families though the degree of assimilation varied. Eventually, four of the five converted; Edward Teller was the only exception. Again, maybe not to equal degrees, conversion was due to expediency. When in 1919, after World War I and the ensuing revolutions, Szilard and his brother wanted to re-enter the Budapest Technical University (called today the Budapest University of Technology and Economics) whose student he had been before he had been conscripted, nationalistic and anti-Semitic students prevented them from entering and beat them up. At that point Szilard produced the certificate about his conversion, but nobody was interested in it. John von Neumann waited with conversion until after his father had died in 1929. There is no evidence that for him it mattered much until his tragic terminal illness of brain tumor, when he sought solace in religious conviction, alas, to no avail. Edward Teller and his bride went for the ceremony of their marriage in a Calvinist church in Budapest to follow her religion—she came from a Jewish family that had converted before, but this, again, made no difference in his world views in which religion did not play a role.

The label Martian underwent some evolution during the 1980s in Hungary. The communist political system was gradually giving way to some relaxation and first hesitantly, eventually with determination, these great scientists became heroes in their home country as well. The physicist George Marx did much to popularize them, and he added many other expatriates who had become successful in the West; the Martians became an umbrella term, extending to economists, movie directors, and even chess players. The impression was sometimes that it was being used also as a euphemism for Jewish origin that would have not been prudent or acceptable to stress. In our usage, however we restrict the meaning of this label to its original group of the five scientists listed above. We adhere to the definition that the Martians were great scientists who were willing even to risk their scientific careers in their efforts of protecting the United States and the Free World from the Nazi menace during World War II and from the communist one during the Cold War.

The five Martians (Figures 1−5) knew each other, but they did not form a group; they interacted among themselves, and today we would call it networking. Their years of birth spans three decades; yet their paths show great similarities, as if they ran along parallel lines. At the time of their youth high school education excelled in Hungary while university education was not remarkable.

There is a popular notion that all five of the Martians went to the same high school. This is not so and Wigner noted in one of his interviews that Budapest was filled with fine high schools. Of the Martians, von Kármán and Teller went to the secular *Mintagimnázium* (Model high school). Von Kármán's father, Maurice was an educational expert and the Model was developed at his initiation as the practicing high school for teachers getting their training at Budapest University. Beyond these two Martians, other future luminaries of science went to this school, such as the physical chemist turned philosopher Michael Polányi, the Oxford low-temperature physicist Nicholas Kurti, and the 2005 Abel-Prize-winner Peter Lax of New York University. The school still exists today in its original building, and continues its participation in teacher's training. Von Kármán was happy remembering the modern approaches in instruction he experienced at this school. A quarter of a century later, Teller's experience was mostly painful as he suffered from the rigid pedagogy in the physics and mathematics classes.

Leo Szilard went to the *Főreálgimnázium* of District VI. It was in a beautiful building completed in 1898 and was modern in equipment and outstanding in teaching staff. The building still stands, but it is sadly abandoned. Szilard's school was a splinter institution from the *Főreálgimnázium* of District V of Markó utca (Markó Street), which produced stellar contributors to the Hungarian and American societies. They included the president of the short-lived Hungarian Republic of 1918−1919, Mihály Károlyi, the financier Gyorgy Soros, the long-time Californian Congressman Thomas Lantos, the chief examiner of the Challenger disaster, mathematician John Kemeny, the future discoverer of holography, Dennis Gabor, and others.

Figure 1. Theodore von Kármán at graduation time from high school. Courtesy of the Archives of the Hungarian National Museum.

Figure 2. Leo Szilard at graduation time from high school. Courtesy of the late George Marx.

Figure 3. Eugene P. Wigner at graduation time from high school. Courtesy of the late George Marx.

Figure 4. John von Neumann at graduation time from high school. Courtesy of the late Ferenc Szabadváry.

Eugene P. Wigner and John von Neumann went to the Lutheran high school, which excelled by having outstanding teachers some of whom conducted independent research. The tuition of the Jewish pupils was multiple times of those of the Lutheran students, but it was deemed still worthwhile and the school had many Jewish pupils. Lászlo Rátz taught mathematics and recognizing von Neumann's talent he gave him private lessons free of charge. Rátz also appreciated the gifted Wigner and gave him books to study. Wigner later noted that he did not match von Neumann's excellence and their teacher made the correct distinction. Von Neumann was one year junior to Wigner. A later pupil, John Harsanyi earned a Nobel memorial prize in the economic sciences.

Figure 5. Edward Teller at graduation time from high school. Courtesy of the late George Marx.

In addition to the above mentioned high schools, we mention the catholic high school of the Piarist Fathers, where among others, two future chemistry Nobel laureates went, George de Hevesy (or, Georg von Hevesy, depending on the language he was using) and George A. Olah. Another future Nobel laureate, Albert Szent-Gyorgyi went to yet another high school in Lónyai Street (today the school bears his name).

Of the five Martians, only von Kármán completed his university studies in Budapest, at the Budapest Technical University. This institution was different from a mere engineering school and provided a broad-based training for him. Generally, Hungarian university education was not on a par with the truly outstanding high school education. Von Kármán graduated still in the "happy peacetime" and started his post-graduate training in Budapest, but then he moved to Göttingen, Germany, to broaden his experience. All the other Martians would also move to Germany in their time, but by then it resembled more an exile than a natural extension of education. Even though the exile was not forced, the atmosphere of general hopelessness reduced the perspectives of all ambitious young people in Hungary, compounded in 1920 by the first anti-Jewish legislation in post-World War I Europe severely restricting the number of Jewish students at universities.

The Martians excelled in their studies and could have completed their university degrees in Hungary but they found the circumstances suffocating. Even during the "happy peacetime" in the enlightened upper-middle-class Jewish families there was an expressed effort to prepare their children for possible emigration. They wanted them to have professions that are usable internationally and they emphasized learning modern languages. Teller's father told his son repeatedly that Hungary had no place for him. Wigner was interested from early on in physics, but when his father asked him how many jobs there would be for physicists, Wigner had to admit that not many; he exaggerated a little and said, four, whereas there were only three and they were all filled. When many years later there was an opening in one, Wigner was considered and then dismissed for it. By then, Wigner was an internationally renowned physicist, but Hungary was a consistently anti-Semitic society.

Below, we will consider each Martian individually, provide a brief characterization as for their characters and introduce the reader to some of their involvements in chemistry and related areas of science.

Theodore von Kármán

Von Kármán's initial interest was in studying engineering and this is what he pursued during his whole life although his engineering was at least as much applied mathematics as designing machines. He arrived in Göttingen in 1906 and embarked on his doctoral studies with the "father of fluid mechanics," Ludwig Prandtl. Following his graduation, he became a coveted member of the scientific elite in Germany. After some other assignments, he continued his research in Göttingen to progress toward his higher doctorate, the so-called habilitation, which was (and is) necessary in Germany for a professorial appointment. He had broad views and interests and attended the exceptionally high-quality research seminars where he met the greats in mathematics, such as Felix Klein and David Hilbert. In establishing these connections, his Hungarian networking helped him, in this case the mathematician Alfred Haar.

Von Kármán became interested in the design of airplane wings, which led to the investigation of vortices. He produced a publication in which he showed that a drag occurs when the air stream cannot stick to the shape of the wing and breaks off behind it into a wake. The result is a series of vortices that soon acquired the name of Kármán Vortex Street. He showed how it can be calculated and how the negative impact of drag can be minimized. Hence came the most advantageous shape—streamlining. This helped also explaining the phenomenon of the so-called singing propeller of submarines. Perhaps the most spectacular application came when he explained the collapse of the Tacoma Narrows Bridge, much later, in 1940 (*4*).

Von Kármán (Figure 6) lived for his professional interest and could be absorbed completely in his work. He liked to entertain and often had large companies in his home, but this did not prevent him from suddenly leaving his guests, withdrawing into his study and getting immersed in a problem that occupied his mind. He was outwardly modest but knew his value, and others did too. Once, when he was invited to Japan to consult and a very high fee was offered to him, he was reluctant to go, and hoped to find his way out of the situation by naming twice the amount as his fee to scare away his would-be hosts. They agreed to the higher fee without hesitation, and he had to go. He liked to appear modest and, of course, he could afford it because his world knew his value and about his achievements.

Figure 6. Theodore von Kármán lecturing. Courtesy of NASA.

William H. Pickering (Figure 7) told us a story that was characteristic of von Kármán's demeanor and his humor. Pickering was a former long-time director of the Jet Propulsion Laboratory (JLP), which had been co-founded by von Kármán and his former pupil Frank J. Malina, who became the first director of JPL. According to Pickering, when twenty years after the original discovery of his vortex streets, a French scientist, Henri Bénard, claimed priority for the same discovery, von Kármán magnanimously suggested that the term "Kármán Vortex Street" be applied to the phenomenon in London and "Boulevard d'Henri Bénard" in Paris (*5*).

Back to von Kármán's Göttingen time, it was Alfred Haar who introduced von Kármán and Max Born (Figure 8) to each other. Eventually, Born became the leading theoretical physicist in Göttingen, one of the creators of quantum mechanics in the late 1920s; he would receive his Nobel Prize in Physics belatedly, in 1954. In Göttingen he and James Franck were the main attractions for young and gifted physicists, like Werner Heisenberg, to congregate and create a revolution in physics. In 1933, the Jewish Born and his family became refugees from the Nazis and settled in the UK.

When Born and von Kármán met around 1910 in Göttingen, they were both Privatdocents—something in between assistant and associate professors in today's terms. They happened to live in the same boarding house, saw each other daily, and liked to discuss research puzzles. They took an interest in the specific heats of solid materials and their relationship to the atomic vibrations in crystal lattices. Of course, the specific heat of a substance is the amount of heat needed to increase the temperature of one gram of that substance by one degree centigrade or one Kelvin; its SI unit is J/gK.

There were some discrepancies between the specific heats from experiment and theory and they wanted to understand them and eliminate them. For this, they took into account the whole spectrum of lattice vibrations, and relied a great deal in their work on group-theoretical considerations. Today, this might seem natural, but at that time it was revolutionary. Their work peaked and was completed in 1911, and the date is significant because at that time there was yet no experimental evidence about the crystal lattice. We have to remember that Max Laue and his associates performed and interpreted the first X-ray diffraction experiment on crystals in 1912, and the two Braggs, William Henry and William Lawrence, came to the idea of X-ray crystallography in 1913 (*6*). Although Peter Debye anticipated the von Kármán-Born results by a few weeks and used a simpler approach that quickly became popular, the more solid work by von Kármán and Born has proved to be of longer lasting value (*7*).

Figure 7. Theodore von Kármán (center) with William H. Pickering (left), former director of the Jet Propulsion Laboratory (JPL) and Frank J. Malina, co-founder and first director of the JPL. Courtesy of NASA.

Their joint experience benefited them both beyond the actual work. Von Kármán always liked challenges and was eager to apply his skills in applied mathematics to a great variety of problems. He developed an excellent sense about how far the approach should be rigorous and approximate in order to find the right solution. He was interested in practical applications of his studies, and even his seemingly most theoretical treatises turned out to be means for solving practical problems. The purely theoretician Born appreciated what he could learn from von Kármán and expressed it eloquently: “to regard the problem in its right perspective, to estimate … the order of magnitude of the result expected before going into detailed calculations, to use approximations adapted to the accuracy needed, … and to be constantly aware of all the facts (*8*).”

There was one more excursion by von Kármán into the realm of atomic and molecular sciences. At about the same time when Niels Bohr came up with his model in which he further developed Rutherford’s atom model, von Kármán also made some attempts along the same lines. He realized that the electron orbits corresponded to distinct energy levels, but failed to reach the conclusion of the electron emitting radiation when jumping from an orbit of higher energy to an orbit of lower energy. He thought that such a suggestion would be too radical, but this failure made him later announce that “in science you must be radical in order to find a new truth (*9*).”

Figure 8. Max Born around the time when he and von Kármán cooperated. Courtesy of Gustav Born, London.

Following his Göttingen time, von Kármán served in World War I, then was an educational officer of high position in the revolutionary governments in 1918−1919 in Hungary. After the failed revolutions, he returned to Germany, made a career there, but left for the United States even before the Nazi takeover. Robert Millikan of the California Institute of Technology (formerly Throop College in Pasadena) invited him first in 1926, but then von Kármán was yet reluctant to go. In December 1929, however, he and his mother and sister left for California, keeping his appointment part time. He broke with Germany after the accession of Nazis to power, but made visits there even afterwards. He also made visits to Japan and may have been responsible for some of the innovations introduced in the Japanese air force. In the 1930s he participated in important civilian projects in the United States. During World War II he wielded tremendous influence over the development of the American air force, which then was still a part of the U.S. Army. He was never in the limelight, unlike, for example, Edward Teller, but his impact on U.S. defense efforts was no less significant than that of any other scientist.

He was instrumental in the realization that air power should be the major means of defending the United States. His vision guided the creation of modern U.S. air power, which was not only strong, but was also strongly rooted in science. The U.S. Air Force was created as a separate service after World War II and von Kármán chaired its Scientific Advisory Board. He advocated strong defense and facilitated the development of missiles that were capable of delivering nuclear warheads. His remaining in the background during fierce political debates did not mean that he was not a strong conservative force behind the scenes. To characterize this we quote two of his statements: One is, “You cannot preach international cooperation and disarmament from a position of weakness. My Old Testament faith tells me that to get one’s point across it is best to have a big stick. You don’t have to use it, but you’re freer to talk without interference.” The other is, “Nothing in my view is so pathetic as an idealistic man talking of situations which he doesn’t have the strength to control (*10*).” Shortly before von Kármán died, President John F. Kennedy awarded him the first National Medal of Science.

Leo Szilard

Leo Szilard (Figure 9) may have been the most colorful of the Martians. He did not live by the rules of conventions and held it that if he had to choose between being tactless and being untruthful, he preferred to be tactless. He was always ahead of everybody else by a few steps. This made him a source of valuable advice for many. Others disliked his mind racing so fast that he would come to conclusions based on other people’s data before those producing the data could have come to them on their own.

Figure 9. Szilard in the company of two future chemistry Nobel laureate Norwegian scientists, Odd Hassel and Lars Onsager, in 1924 in Berlin−Lichterfelde. Photo by Johan P. Holtsmark; courtesy of the late Otto Bastiansen.

Szilard was interested in physics, but early on understood that it was not a viable profession in Hungary. He could opt for chemistry, but family members convinced him to study engineering instead. This came handy for him when he worked on the world's first nuclear reactor and on his numerous patents throughout his career. World War I interrupted his studies at the Budapest Technical University, and after the war, he immigrated to Germany.

Szilard understood better than most the unreasonable character of the war and predicted the defeat of Germany and Austria−Hungary as well as the defeat of Russia. The bizarre in this was that Germany and Austria−Hungary, called also the Central Powers and Russia were on opposite sides of the war, yet Szilard proved to be right. From January 1920, Szilard lived in Berlin, the capital of Germany and one of the capitals of modern physics. Szilard started at the Technical University but soon gravitated toward the science university because it boasted such greats as Max Planck, Max von Laue, Walther Nernst, Fritz Haber, Gustav Hertz, and James Franck. Albert Einstein worked at the Kaiser Wilhelm Institute in Berlin−Dahlem, but came regularly to the University to attend its famous weekly colloquia. Other young attendees included Erwin Schrödinger, Wolfgang Pauli, Werner Heisenberg and others. Szilard was not intimidated by the presence of the greats; rather, he told the revered Planck that he was interested in the facts only, because he intended to create the theories himself. This happened still in Szilard's first year in Berlin. Eugene P. Wigner was another Martian who attended these colloquia and Dennis Gabor, also from Budapest, was there too; many years later, he was to become a Nobel laureate for his discovery of holography.

Szilard worked on his doctoral dissertation formally under Max von Laue, but he did not follow von Laue's recommendation for his project. Instead, he decided to investigate the heretofore not yet recognized implications of the Second Law of Thermodynamics. He was looking for some broader applications, and when he found them, he wrote up his dissertation. Before submitting it to von Laue, he showed it to Einstein, who was quite puzzled initially by Szilard's suggestion, but soon enough accepted them with enthusiasm. The Second Law prescribes simultaneous energy decrease and entropy increase, but Szilard described the emergence of more ordered systems in a closed system without violating the Second Law. Szilard's treatment included the concept of information transfer although not yet by that name—it would come decades later, for example in von Neumann's studies on automata with considerable military applications in the determination of the reliability of missiles.

After his first doctorate, Szilard quickly acquired his higher doctorate according to the German system. The corresponding two publications served their purpose earning Szilard his desired degrees, but then he abandoned these studies. It was typical of his entire career. He did not linger on topics and often concluded them with a patent rather than a publication, and then moved on. He came to the ideas of several inventions that he patented, but then others developed the same or similar inventions; such were the linear accelerator and the cyclotron. He and Einstein submitted several patents on a new refrigerator, including a new pump working on electromagnetic principle, which was later utilized in nuclear reactors.

Einstein and Szilard became quite close; that was special because neither was known to forge intimate friendships. They shared not only patents but also interests in such fields as cosmology and religion. They agreed that “As long as you pray to God and ask him for something, you are not a religious man (*11*).” They wanted to find out God’s initial thoughts in creating Nature. Once they would succeed in that, they thought they could figure out the rest. They both admired the teachings of Spinoza, the seventeenth century Dutch philosopher. Einstein may have come closest to understanding Szilard who remained an enigma for most of his friends for his entire life. He was not a recluse; on the contrary, he always led an active social life, was always in the midst of the most active scientists and was peripatetic during his entire life.

When refugee scientists flooded Great Britain and were looking for safe havens also in the United States, Szilard—who himself became a refugee—did an extraordinary organizational work to help placing them. He certainly considered it more important to assist others than to worry about his livelihood, let alone his scientific career. He was unwavering in his priorities. He spent most of his time in London from the Nazi takeover in Germany until the outbreak of World War II. He vowed that he would depart from Europe to America one year before the start of the war—his friends were amazed by how anybody could know one year in advance about the beginning of the war—but this is exactly what happened. When Szilard, while on a visit in the United States, learned about the Munich Agreement between Nazi Germany and Great Britain and France, signed on September 30, 1938, he decided not to return to Europe. World War II broke out on September 1, 1939.

While still in England, Szilard was very creative. He found the English lifestyle and demeanor very comfortable. He came into collision only with one man, but that was Ernest Rutherford. On September 11, 1933, in a public lecture Rutherford issued a warning “to those who look for sources of power in atomic transmutations—such expectations are the merest moonshine (*12*).” This upset Szilard, because he did not think anybody could know what others might or might not invent. Indeed, Szilard came to the idea of the nuclear chain reaction: “if we could find an element which is split by neutrons and which would emit *two* neutrons when it absorbed *one* neutron, such an element, if assembled in sufficiently large mass, could sustain a nuclear chain reaction” (italics in the original). Here Szilard arrived at two concepts. One was the nuclear chain reaction—it was really a nuclear branched reaction—and the other was the critical mass.

Chain reactions had been known in chemistry. The reaction between hydrogen and chlorine, $H_2 + Cl_2$, could serve as an example, which Walther Nernst interpreted as a chain reaction. Then the idea of branched chain reactions was arrived at in the interpretation of the reaction of the oxidation of phosphorus. Yulii B. Khariton conducted the initial experiments in the mid-1920s in Moscow, and Nikolai N. Semenov worked out the full theory. The Semenov−Khariton branched chain reaction ends in an explosion under the right conditions. Szilard’s concept of the nuclear chain reaction is also a branched chain reaction, which was sustainable, but could also end in explosion. Semenov’s and Khariton’s publications were available in the Western literature in German and in English. We do not know whether or not Szilard was familiar with them; we find it likely that he was not.

Szilard did not publish his discovery of the concepts of nuclear chain reaction and the critical mass; rather, he patented his findings. He must have understood the military implications of his patents and did not let them become publicly available. Rather, he deposited his patent with the British Admiralty. Parallel to patenting, he was looking for the possibility to conduct some experiments. He was fully aware of the missing information that would hinder the direct application of his concepts. The main obstacle was that he did not know which element would be the one that would emit two neutrons after having absorbed one. He also realized the importance of isotope separation. He was afforded the possibility to build some experiments at St. Bartholomew's Hospital, which was a teaching institution in London, provided that a staff member of the institution would join him in his endeavor. Szilard and Thomas A. Chalmers invented a simple method of isotope separation and within weeks, they already had a manuscript for *Nature* (*13*). The resulting Szilard−Chalmers Effect has proved to be widely applicable.

When in the very beginning of 1939 Szilard learned about the discovery of nuclear fission in uranium, he knew that uranium was the element for his nuclear chain reaction. He at once involved himself in experiments together with Enrico Fermi and others at Columbia University, which showed that uranium absorbing one neutron could emit two, and sustained nuclear chain reaction and, accordingly, energy production was possible. He also realized that in the absence of proper control, the reaction could lead to explosion, if sufficient mass of uranium was available. For the proper control, he determined that absolutely pure graphite was necessary as a moderator. In the meantime, other laboratories have also reported that in the fission reaction, the number of emitted neutrons was greater than the number of initially bombarding neutrons.

Parallel to his experimental work, Szilard was concerned with the possible political and military implications of the new discoveries in nuclear matters. He especially worried about the possibility of Germany acquiring a bomb based on the principles of uranium fission and nuclear chain reaction. Enlisting the assistance of fellow Martian Eugene P. Wigner and then Edward Teller, he engineered a letter by Einstein to President Franklin D. Roosevelt calling his attention to this danger and suggesting the establishment of direct interaction between his Administration and the nuclear scientists. This could be considered the seed of what later developed into the Manhattan Project.

Initially Szilard's principal goal was to anticipate a possible German nuclear weapon. For some time, he found deployment of the atomic bombs desirable still in World War II, even if a German bomb would not materialize. In this he was guided not only by military considerations of the ongoing war, but by the necessities of the post-war situation. He thought that in order for the international community to realize the potentials and hazards of nuclear weapons, the world should witness it in action. Toward the end of the war when the deployment of the bomb drew closer to reality, he started a movement to oppose direct bombing; instead, he was for the demonstration of the bomb. Szilard was an idealist and did not have a full picture of the situation; he did not seem to be aware of the powerful elements in the Japanese leadership that were ready to prolong the fighting regardless of the losses. As it happened, the uranium and the plutonium bombs were exploded over Hiroshima and Nagasaki, and the war came to a quick conclusion, saving perhaps millions of American and Japanese lives. It also had important implications for the post-war international situation. Of course, this is an oversimplified aspect of what happened and the story has a vast and controversial literature. Szilard's actions had immense consequences.

After the war, and after some involvement in the American political debates about the way matters of nuclear weaponry and nuclear energy should be handled, Szilard, for a while, entered biological research and interacted with leading biologists (Figures 10 and 11). They had a virtually endless resource of ideas and advice, but he also involved himself and one associate, Aaron Novick, in research projects that included laboratory experimental work. He quickly learned up-to-date techniques and then came up with original ones. Szilard and Novick, for example, invented the chemostat, which served as a continuous source of bacterial population for experiments. Another of their results was a methodology for accurately measuring the rate of mutation of bacteria. Their discovery of feedback inhibition helped understanding the intracellular processes of metabolism and growth.

Figure 10. Leo Szilard and Alfred Hershey at Cold Spring Harbor Laboratory around 1950. Courtesy of Karl Maramorosch, Scarsdale, NY.

After a while, however, Szilard gave up direct involvement in experimental research and returned to dealing with various issues of society. He led an active social life and was always in the center of any gathering he attended (Figure 12). He initiated or participated in initiating important projects and institutions. They included the Salk Institute for Biological Studies, the National Science Foundation, the Pugwash Conferences on Science and World Affairs, the European Molecular Biology Organization (EMBO), and the European Molecular Biology Laboratory (EMBL).

Figure 11. Leo Szilard and Jonas Salk in Cold Spring Harbor in 1953. Courtesy of Karl Maramorosch, Scarsdale, NY.

Figure 12. Leo Szilard in the center, with Laura Polanyi and others in the 1950s. Courtesy of the Hungarian National Museum.

Szilard was a champion of the peaceful coexistence of the United States and the Soviet Union. He made efforts to this end and used a great deal of personal diplomacy, even interacted with the Soviet leader Nikita S. Khrushchev. However, it would be a mistake to think that he would have supported unilateral disarmament of the United States. Also, in a lecture given in 1954, he unambiguously declared that during the big debate at the end of 1949 among the scientists whether or not the United States should develop the hydrogen bomb, he rooted for Teller. He knew that a totalitarian regime, like Stalin's Soviet Union would blackmail the Free World if it had been in a position of military advantage. He had, however, fierce debates with Teller about mutual disarmament and especially advocating banning testing further nuclear devices and the peaceful utilization of nuclear energy (Figure 13).

Figure 13. Leo Szilard and Eugene P. Wigner at a press conference on nuclear energy at Oak Ridge. Courtesy of Oak Ridge National Laboratory.

Throughout his life Szilard waged a lonely fight for what he thought was right. He engaged in any activity that he thought would advance the cause of peaceful progress. He even wrote sci-fi literature, *The Voice of the Dolphins*, when he felt this way he could reach people who otherwise did not respond to his worries. He had the potential of a great scientist and the few discoveries that he made were milestones, especially the concept of nuclear chain reaction and critical mass. However, achievements in research were not his main goal. He "lived in two worlds throughout his adult life. He scrutinized every development in science from the point of view of the possible consequences of those developments. In one of his worlds he tried to predict what was going to happen and this concerned not only science but everything else as well. In his other world he fought for what he hoped would happen. This second world took precedence over the first one and this second world was the source of his activism. When the idea of the nuclear chain reaction came to him, he at once felt the tremendous responsibility of being in the possession of this concept that might lead to the most devastating calamity in the wrong hands, but might also become the instrument of saving the democracies in their fight against evil (*14*)."

Eugene P. Wigner

Eugene P. Wigner started his university studies in chemical engineering at the Budapest Technical University, but in 1921, he left Hungary for Germany. He continued his studies in Berlin in chemistry at the Technical University. The instructions were quite traditional; in the inorganic chemistry course, instead of electrons orbiting the nucleus, he learned about materials and properties. He did not know then, but realized eventually that it was easy for him later to catch up with the modern structural aspects of chemistry, but what he learned about materials would be invaluable when working on nuclear reactors. Wigner was a very conscientious chemistry major. Being aware that his father directed a tannery in Budapest and that he would expect his son to join him there as chemical engineer, Wigner took special courses that he thought might be useful in the tannery. Nonetheless, he had fascination only for physics, and he performed merely to a satisfactory level in his chemistry courses.

As Szilard before him, Wigner also recognized in Berlin that the University and its weekly colloquia provided a unique opportunity for him to immerse himself in his beloved physics. Wigner met Einstein through Szilard and visited him often in his home. They talked about physics as well as about social and political questions. In the meantime, Wigner continued his chemistry studies and acquired his Diploma in Chemistry (equivalent with a Master's degree) and his doctorate. Hermann F. Mark was his mentor for his Diploma Work and the project was the symmetries of the rhombic sulfur crystal. This is how he initially embarked on symmetry studies, which then became a life motif for him. Although Wigner was a student of the Technical University, he carried out his research at the Kaiser Wilhelm Institute in Berlin−Dahlem where Mark had a position under Michael Polanyi.

Wigner was an excellent student and it was only natural that he would continue as a doctoral student. For his doctoral project, Polanyi took over as mentor and they studied the processes of two atoms joining in a molecule and of such molecules breaking up. In their joint studies, Polanyi and Wigner utilized Bohr's atom model and extended its applications to treating aspects of molecular science. They produced results on the rates of formation and decomposition of molecules and on the rates of the two processes (*15*). Wigner soon acquired his doctorate and returned to Budapest. A few years later, back in Berlin (see below), Polanyi and Wigner continued their joint work and focused on the importance of molecular vibrations in molecular structure (*16*).

It was immediately after Wigner having acquired his doctorate in chemistry in Berlin that he returned to Budapest and as a well-behaving son, took up his position in the tannery directed by his father (Figure 14). Even decades later, he was proud of his knowledge of the chemical processes involved in tannery and of the different ways of preparing the leather. However, Wigner could not warm to his job and longed for challenging research projects and the scientific atmosphere of his Berlin environment (*17*).

After hardly more than one year in the tannery, in 1926, he had the opportunity to return to Berlin to work with the crystallographer Karl Weissenberg at the Kaiser Wilhelm Institute. Polanyi engineered the invitation for Wigner. Weissenberg was interested in crystal symmetries and asked Wigner to immerse in group theory; this proved greatly beneficial for Wigner's career. Both von Neumann and Szilard provided assistance for Wigner; von Neumann in mathematics and Szilard with general encouragement and advice. Wigner and Witmer's paper in 1928 contained the first application of symmetry considerations to chemical reactions. The Wigner–Witmer rules referred to the conservation of spin and orbital angular momentum in the reactions of diatomic molecules (*18*). Wigner's interests in group theory on the one hand, and in quantum mechanics, on the other yielded a combined result when he produced his classic *Group Theory and Its Application to Quantum Mechanics of Atomic Spectra* (*19*).

One of the present authors (IH) received great encouragement from interactions with Wigner. The initial contact happened in 1964 when Wigner responded with a kind and long letter to an article by IH in a Hungarian literary periodical. The interactions culminated in a personal meeting and extended conversations in 1969 at the University of Texas at Austin (Figure 15). It was IH's introduction to the broader aspects of the symmetry concept to solving research problems in molecular structure studies. It was also about broader applications (*20*). The ensuing on–and–off correspondence throughout the years contributed to the creation of a monograph on symmetry in chemistry (*21*).

Figure 14. Eugene P. Wigner (in the back) in 1925 with workers of the Budapest tannery. Courtesy of the late Martha Wigner Upton.

Figure 15. Eugene P. Wigner and István Hargittai in 1969 on the campus of the University of Texas at Austin. (by unknown photographer).

Wigner was a much-respected scientist, and he was awarded the Nobel Prize in Physics in 1963. He received half of the prize that year and the other half went jointly to Maria Goeppert-Mayer and J. Hans D. Jensen “for their [independent] discoveries concerning nuclear shell structure.” The motivation of Wigner’s award was a little more elaborate, “for his contributions to the theory of the atomic nucleus and the elementary particles, particularly through the discovery and application of fundamental symmetry principles.” Nobody had any doubt that Wigner deserved the distinction; in fact, many had expected, for years, his award. However, the Nobel Prizes, according to the letter of Nobel’s Will, go for distinct discoveries rather than just to great scientists for their life’s oeuvre.

For appreciating Wigner’s contributions to science through his symmetry studies, we call on some authorities. According to Nobel laureate Steven Weinberg, “Wigner realized, earlier than most physicists, the importance of thinking about symmetries as objects of interest in themselves. Wigner was able to transcend [the specific theories of nuclear force] and he discussed symmetry in a way, which didn’t rely on any particular theory of nuclear force (*22*).” Another Nobel laureate, David J. Gross emphasized the fundamental relationships worked out by Wigner, from the symmetry principles to the laws of nature to the physical phenomena (*23*).

On the background of Wigner’s achievements in theoretical physics, it is easy to overlook his most practical contributions to the U.S. military might in creating the first atomic bombs and his work at Oak Ridge immediately after World War II. Still back in Germany, once he had detached himself from the work in the Budapest tannery, he happily immersed himself in projects of pure theory. He spent some time in Göttingen as David Hilbert’s assistant, and then taught quantum mechanics in Berlin. He was not an excellent lecturer there and later in Princeton either. It followed from his personality that he constantly worried that some of his students might not understand what he was explaining and this made his lectures exceedingly slow. However, his students found him a profound mentor and he would have stellar students, future leaders among American physicists, in Princeton.

Wigner received his first invitations from Princeton a few years before Hitler’s accession to power in Germany; first, he had a joint appointment between Princeton and Berlin, which changed eventually to full time appointment in Princeton. In 1934, he spent a year with Michael Polanyi in Manchester, UK, where Wigner’s former mentor had moved (Figure 16). When Princeton University did not give him the appointment he had hoped for, he resigned and moved to the University of Wisconsin. He was happy there, but after a few years time he moved back to Princeton and stayed there as a most revered professor to the end of his life.

Wigner participated in the development of the American atomic bombs from the start. As a former refugee, he realized more than most of his colleagues the dangers of the Nazi menace. He became the head of a theory group charged with designing the nuclear reactor at Hanford, Washington, whose goal was to produce plutonium-239 (this was to be the fission fuel for the bomb over Nagasaki). His background as chemical engineer greatly facilitated his solving this task successfully, and other tasks that followed.

Figure 16. (from left to right) John C. Polanyi, Michael Polanyi, and Eugene P. Wigner in 1934 in Manchester, England. Courtesy of John C. Polanyi.

After the war, Wigner became director of research and development at the Clinton Laboratory in Oak Ridge, Tennessee. His project employed about four hundred people and Wigner, once again, enjoyed that he could be involved in practical engineering. In this period, he participated in numerous patents connected with the design and operation of nuclear power plants. After a couple of years, however, he decided to return to teaching and independent research and resumed his professorship at Princeton. His involvement in defense matters was mostly through his advocacy of the importance of civil defense.

Wigner was a character and he had his admirers as well as his detractors. Szilard called him the conscience of the Manhattan project. He considered Wigner a fighter; others found him stubborn. The trait most people readily associate with Wigner is politeness. At scrutiny, one might have the impression that his politeness also served to keep people at a distance from him. Even his fellow Martians might not have been his friends as most of us interpret this term. His politeness could also camouflage his true intentions. He could appear modest and apologetic at a seminar while setting a ruthless trap for the speaker. He was a dedicated conservative and could appear biased and opinionated. In the 1969 conversations with one of us, alluded to already above, he could not accept that there might be poverty in the United States. As proof, he suggested to visit his home environment, Mercer County in New Jersey. IH did not know at that time that Mercer County was among the most well to do counties in the whole country. Wigner's fierce political stand angered the student anti-war protestors during the Viet Nam War when he declared that their abusing him was a compliment for him (Figure 17).

Wigner revered his teachers. There was a photograph of Laszlo Ratz, his high school math teacher on the wall of his Princeton office (Figure 18). He mentioned him in his two-minute Nobel Banquet talk. His entire speech was devoted to teachers about whom he said that we think little about them when we are young, but appreciate increasingly along our intellectual development. He also singled out Michael Polanyi who taught him what science was, von Neumann from whom he learned a great deal of mathematics, and Ray Herb from whom he learned leadership.

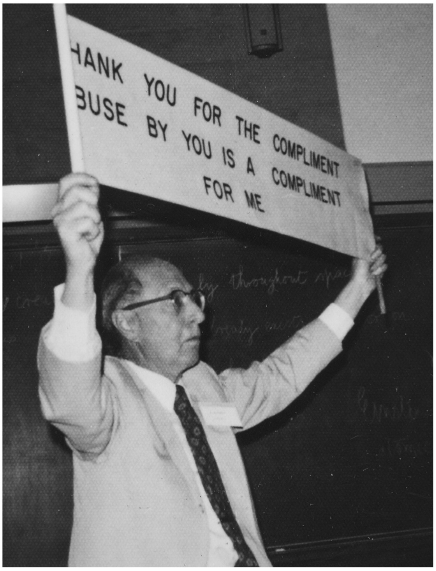

Figure 17. Wigner unfolds his poster in opposition of students protesting against the Vietnam War. Courtesy of the late George Marx.

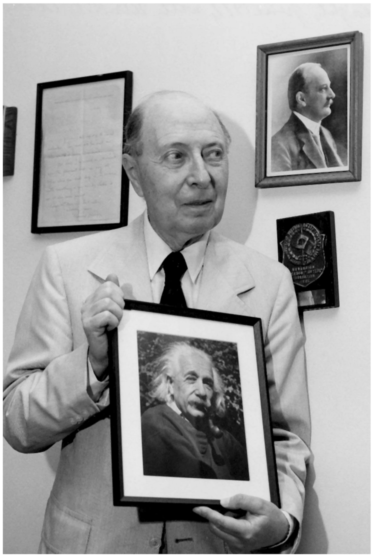

Figure 18. Wigner showing a photograph of Albert Einstein taken from the wall of his office. In the background, on the wall the portrait of Lászlo Rátz, his high school math teacher is visible. Courtesy of the late George Marx.

In Characters in Chemistry: A Celebration of the Humanity of Chemistry; Patterson, G., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

Gerhard Herzberg said of Eugene Wigner: “Eugene Wigner is claimed by physicists as well as chemists, as one of their great pioneers (*24*).”

John von Neumann

Von Neumann’s special gifts in mathematics manifested themselves from his childhood, yet initially he did not embark on a career in his favorite subject. At his parents’ insistence, he chose chemical engineering and studied chemistry in Berlin and Zurich. Parallel to his chemistry studies he earned a doctorate in mathematics from Budapest University. He settled in Germany, held an academic appointment, but in spite of finding the arrangement fully satisfactory, he sensed as early as the mid-1920s that the conditions in Europe would be worsening and there might be another war coming. He also sensed that considering the growing economic prowess of the United States it was inevitable that the country would strive to a leadership position in science. Von Neumann proved to be tremendously productive in the 1920s, but had an open eye and an open mind, and when an invitation came from Princeton, he was ready to move. The appointment first was on a part time basis and both he and Wigner alternated between Princeton and Germany, but the situation changed with the Nazis coming to power, and von Neumann settled in the United States for good. He felt comfortable in his new home country; its informal style of life agreed with him (in contrast with Wigner who did not feel the informality comfortable). Besides, von Neumann became a professor of the recently established Institute for Advanced Study, which was even more informal than the American universities. Von Neumann, again, proved to be very productive. He dealt with a plethora of problems, was considered to be a genius, or even possessing a more advanced modification of brain—sort of a mutant—than the rest of humanity. His interest and talent extended to the most diverse fields of the applications of mathematics. When the U.S. war efforts involved his participation, he did not let any specific project bog him down; rather, he became a sort of roving ambassador and moved from project to project, making himself immensely useful.

On one of these occasions, as he was visiting Los Alamos, the laboratory for the final stages of the production of the first atomic bombs, he was confronted with the technical problems of the plutonium bomb. Today we might consider this problem belonging to materials engineering. His studies of chemical engineering might have proved useful in this case. The gist of the problem was that plutonium had a tendency for spontaneous explosion in amounts much below its critical mass. This is why the implosion method was suggested rather than the gun-shot method applied to the uranium bomb in which case at least one of the two pieces of sub-critical mass was still to be fairly large.

For the plutonium bomb, they had to bring together more than two pieces of the fission material within an incredibly short time. There were two challenges; one was to make sure that they used the smallest possible total mass for the bomb. The other was to establish the geometry for the implosion that ensured uniformity from all direction for the implosion. There are versions of how they found the solution, but all emphasize von Neumann’s role in it. To be sure, von Neumann did not initiate the technique, its idea had already been around for some time when he became acquainted with it, but gave valuable guidance in its accomplishment.

In Edward Teller's description, von Neumann attended a talk about implosion during one of his visits to Los Alamos. He became interested in it, and von Neumann and Teller started some rudimentary calculations about the compressibility of solid materials. It is school material that solids cannot be compressed, liquids slightly, and gases are greatly compressible. However, this is not so, because it is known that even metals such as iron have higher densities in the center of the earth, under the tremendous pressure, than on its surface. Thus, among conditions of very high pressure, higher densities would characterize the fissionable material hence the amount of critical mass would be smaller than at ordinary pressure. They also discussed the geometry of the implosion and stressed the importance of high symmetry to ensure maximum efficiency. Not even von Neumann could guess everything in solving all problems of implosion, and he pointed to the necessity of computers. His advocacy of fast computers in this case and numerous other cases became his trademark. He is best known for his creative work in developing the modern computer and in particular for his contribution to producing the stored program computers (Figure 19).

Figure 19. John von Neumann, Robert Oppenheimer, Herman Goldstein, and Julian Bigelow in front of the computer at the Institute of Advanced Study in Princeton. Photo by Alan W. Richards; courtesy of Marina von Neumann Whitman, Ann Arbor, MI.

He did not have a warm personality and even people who were closest to him, like Eugene P. Wigner, noted the lack of warmth and sensitivity in his human interactions. He lived in his inner world and let the outside into it to the extent that was necessary not to become an outcast. He was hardly ever interested in the affairs of his fellow human beings. It would happen that he was rigidly staring at a woman sitting across the table to the extent that she started feeling embarrassed. It turned out that he was not staring at her; he was merely deeply immersed in his own thoughts and oblivious of anybody sitting across the table. Von Neumann though was a very active participant in scientific meetings and the social life of scientists (Figures 20 and 21).

Figure 20. (from left to right) Leo Szilard, Sol Spiegelman, Fritz London, John von Neumann, Edward Teller, and Niels Bohr at a theoretical physics meeting in 1946 in Washington, DC. Courtesy of Marina von Neumann Whitman, Ann Arbor, MI.

Politically, von Neumann may have been the most hawkish among the Martians. He advocated preemptive strikes against Moscow soon after World War II while the United States still had superiority in nuclear weapons. His popular image, however, did not quite reflect his politics, because he preferred staying in the background. He always watched out for public relations. When, in 1954, he testified in the Oppenheimer hearing, he was careful not to accuse Oppenheimer lest he alienate his colleagues. Von Neumann was involved in shaping U.S. military policy and was especially instrumental in developing the American ballistic missile capabilities that made it possible to deliver nuclear warheads virtually to any location on earth. When in 1955 President Dwight D. Eisenhower appointed von Neumann as a member of the U.S. Atomic Energy Commission, he became the highest-ranking Martian in an American administration. It was then a tragedy that in his early fifties, he succumbed to a brain tumor, and this most intelligent member of his generation had to witness the gradual decline of his own intelligence. He was already bound to a wheelchair when in 1956 President Eisenhower awarded him the Medal of Freedom (Figure 22).

Figure 21. Participants of the Shelter Island meeting of theoretical physicists in 1947, from left to right, Isidor Rabi, Linus Pauling, John Van Vleck, Willis Lamb, Gregory Breit, Duncan McInnes, K. Darrow, George Uhlenbeck, Julian Schwinger, Edward Teller, Bruno Rossi, Arnold Nordsieck, John von Neumann, John Wheeler, Hans Bethe, Robert Serber, Robert Marshak, Abraham Pais, Robert Oppenheimer, David Bohm, Richard Feynman, Victor Weisskopf, and Herman Fershbach. Courtesy of Marina von Neumann Whitman, Ann Arbor, MI.

Figure 22. John von Neumann receiving the Medal of Freedom from President Dwight D. Eisenhower in 1956 at the White House. Courtesy of Dwight D. Eisenhower Library, Abilene, KS.

In Characters in Chemistry: A Celebration of the Humanity of Chemistry; Patterson, G., et al.; ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

Edward Teller (*25*)

Edward Teller grew up amidst a loving family, but he felt lonely. His friends were the numbers and he started talking relatively late. He was not popular among his peers in school, but became popular during his years in Germany and later during his first years in the United States. His prima donna character first manifested itself during the Manhattan Project in Los Alamos when he declined doing some routine calculations.

His fierce anti-communism developed during his time in Los Alamos and continued throughout his life. However, it was more political than ideological; it was more anti-Soviet than directed against the ideals of communism. His personality underwent changes. From the early 1950s, he no longer seemed to be concerned with how his peers considered him. When his colleagues opposed his goals, he turned against them with any means available to him.

In 1954, he testified against J. Robert Oppenheimer in such a calculated way that his words remained imprinted in the minds of his friends and foes alike. Oppenheimer's downfall is often ascribed to Teller's testimony. However, by then, the government's representatives had destroyed Oppenheimer's veracity, and Teller's testimony brought more harm for Teller than for Oppenheimer. Teller later claimed that certain information made his testimony more negative than he had planned. The truth, however, was that he had some time before vowed that he would do most anything to have Oppenheimer removed from his positions of decision-making.

Teller opposed the test bans and recklessly used certain arguments and diametrically opposite ones if he deemed them more effective. In connection with the Strategic Defense Initiative (SDI), he misled the government with unrealistic promises and tried to destroy those who pointed out his fallacy. Whether appreciating or deploring, no administration and no American president could ignore Edward Teller in their dealings with nuclear matters (Figure 23)

Once we remove, though, the personal animosities, and Teller's Machiavellian demeanor in some of his dealings, we have to admit that he considerably contributed to the might of the United States. The facts remain that the American hydrogen bomb that he helped develop contributed to a power balance with the Soviet Union, which would have developed its own hydrogen bomb regardless of the American intentions. We believe that this balance of power was essential to maintain peace for decades between the two superpowers. More controversial is the question whether or not SDI may have contributed to the demise of the Soviet Union. We maintain that it did or at least accelerated it. Although the presidents of the two superpowers viewed Teller's activities in opposite ways, they both recognized the importance of his activities (Figure 24).

Figure 23. White House ceremony in 1962 on the occasion of John F. Kennedy distinguishing Edward Teller with the Fermi Award; from left to right, Glenn T. Seaborg, Edward Teller, John F. Kennedy, and Mici Teller. Courtesy of John F. Kennedy Library, Boston.

Figure 24. Soviet president Mikhail Gorbachev, President Ronald Reagan, and Edward Teller at the White House reception, 1987. Courtesy of Ronald Reagan Library, Simi Valley, CA.

Teller could be charming, caring, and helpful when there was no conflict with his aims. He stood up to McCarthyism when his friend Stephen Brunauer (Figure 25) came under attack, and when one of his colleagues was prevented from teaching at a university because of his communist views, Teller found it important to defend his freedom of thought.

Figure 25. Stephen (István) Brunauer in his U.S. Navy uniform. Courtesy of Burtron Davis, Lexington, KY, and Dalma Hunyadi Brunauer.

Teller was an excellent physicist with a thorough chemistry background from his earlier studies. He was successful in solving problems in physical chemistry/chemical physics. He seldom worked alone; rather, he preferred working with someone else, and he was generous in sharing credits for research achievements. He was not at the very top among the physicists of the scientific revolution in the first half of the twentieth century, but was certainly in the next echelon, like Oppenheimer, Hans Bethe, George Gamow, and others. His most outstanding results were in nuclear physics, but what he accomplished in molecular chemistry would have sufficed for a separate outstanding career. We quote from among these results below.

Teller switched from chemical engineering to physics in his studies during the late 1920s. He did his doctoral work under Werner Heisenberg in Leipzig where he came across such luminaries of molecular chemistry/molecular physics as Friedrich Hund and Robert Mullikan (Figure 26). When the Nazis came to power in Germany, Teller, a Hungarian citizen, could have stayed on, but he decided to leave. First, he spent some time in Niels Bohr's group in Copenhagen, then at the University of London, before in 1935 he immigrated to the U.S., to George Washington University, Washington, DC, as full professor of physics.

Figure 26. Robert Mulliken and his wife, Béla Pogány (a professor at the Budapest Technical University) and Edward Teller in Budapest. Courtesy of the late George Marx.

In London, Teller and Bryan Topley studied a simple chemical reaction, the hydrogenation of ethylene to ethane, and calculated the changes of heat content for which conflicting experimental data had appeared. The different results implied very different barriers to internal rotation in ethane. Although the general view at the time favored free rotation, Teller and Topley supposed hindered rotation and kept assuming higher and higher barriers until they reached a value of 3 kcal/mol (*26*). At this point, they found consistency with experimental data. It was certainly a brave step to come out with such an estimate, about which today we know that it is about right.

Indications are that Teller himself probably considered the famous BET equation to be his most important result in chemistry. BET refers to Stephen Brunauer (Figure 25), Paul H. Emmett, and Teller. This piece of research happened already during Teller's American period and the first report appeared in 1938 (*27*). It was about multilayer adsorption. They built up the description layer by layer, based on previous work by Irving Langmuir who had worked out the adsorption of the first layer of molecules on the surface. This was an entirely new topic for Teller, but when the question arose, he proved ready to face its challenge (*28*).

The wide applicability of the BET equation was due to its use in the determination of surface areas (*29*). Teller usually never returned to topics with which he had been involved and solved successfully. However, the BET equation was an exception as he was among the numerous researchers who tried to improve upon this most useful tool in physical chemistry (*30*). Even the latest reports have not changed much the original formulation of the BET equation.

Lately, the fame of the Jahn−Teller effect may have overtaken that of the BET equation due to its broadening applicability and its conspicuous role in the discovery of high-temperature superconductors. We talk about the Jahn−Teller effect, when we have a highly symmetrical molecule whose orbitals are not completely filled with electrons. In such cases, there is a mismatch between the molecular geometry as determined by the configuration of the atomic nuclei and the symmetry of the electron density distribution. This causes some of the nuclei to move from their original positions into ones that match the symmetry of the electron density distribution; hence, the symmetry of the molecule decreases (Figure 27) (*31*).

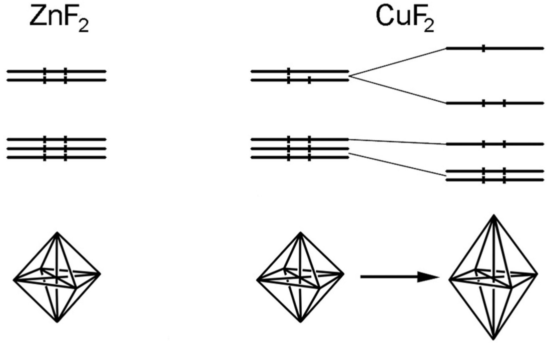

Figure 27. Illustration of the Jahn−Teller effect. The horizontal lines represent energy levels; the vertical ones represent electrons. In ZnF_2 there is no effect as all the energy levels are filled by electrons. In CuF_2, the electrons do not completely fill the energy levels; instead of the regular octahedral shape the symmetry of the molecule lowers, it takes an elongated shape—this is a manifestation of the Jahn−Teller effect.

The Jahn−Teller effect does not apply to linear symmetrical molecules, such as carbon dioxide. Its symmetry was the subject of a separate study by one of Max Born's doctoral students, Rudolf Renner (Figure 28) in the early 1930s. When Born had to flee Germany and Teller was still there for a short while, he helped Renner complete his work that showed that although in its ground state carbon dioxide is linear; it bends in its excited electronic state due to what is called now the Renner−Teller effect (*32*).

Figure 28. Rudolf Renner (1909−1991). Courtesy of Beate Bauer−Renner, Renner's daughter-in-law, Dorum, Germany.

Actually, while still in Copenhagen, Teller had discussed the possible symmetry lowering in certain types of molecules with the Soviet physicist Lev Landau. That time they could not yet completely explain the different distortions. Nonetheless, Teller always emphasized Landau's merits in the understanding of these changes. Hermann A. Jahn (Figure 29) and Teller interacted when Teller was at University College London and Jahn was at the Royal Institution (*33*). Their work has been frequently cited. The discoverers of high-temperature superconductors, J. Georg Bednorz and K. Alex Müller, in their Nobel lecture paid tribute to the Jahn−Teller effect in having embarked on the project that finally led to their discovery (*34*).

Figure 29. Hermann A. Jahn (1907−1979) in the early 1930s. Courtesy of Michael Jahn and Margaret May, Jahn's son and daughter, London.

Teller's background in chemistry made him more receptive toward problems of the structure of biological macromolecules. At the initial stage of the search for the genetic code, he suggested one. It proved to be erroneous, yet it showed his broad interests. The code he suggested—it was in 1954, at the trying period of the Oppenheimer hearing—would define each amino acid using two bases and the previous amino acid in the chain. In Teller's model, the DNA molecule served as a physical template (*35*).

In 1972, Teller gave an invited talk to the sixteenth Robert A. Welch Foundation Conference on Chemical Research. The topic of the sixteenth meeting was "Theoretical Chemistry" and the title of Teller's presentation was "Lasers in Chemistry (*36*)." The participants received Teller's talk very well, and it generated vigorous discussion. He combined his deep understanding of the topic with an easy-to-digest style that was his trademark. At some point, he brought up the topic of X-ray lasers that did not yet exist. The X-ray laser would produce high-intensity X-rays, much more powerful than the conventional light laser due to the much shorter wavelength and much higher energy of the X-rays. Teller considered potential applications of the X-ray laser. He did not mention weaponry; rather, he pointed to a purely basic research use, viz., unsolved problems in crystal structure analysis. His meaningful discussion of the use of a technique that did not yet exist was impressive.

Our concluding example of Teller's chemistry-related studies concerns the benzene structure and the theory of resonance. In the 1930s, Linus Pauling applied the resonance approach to explain that two equivalent structures in which single and double bonds alternated could equally well describe the structure of the benzene molecule. Of course, Pauling's explanation did not suggest the presence of two separate structures; it only provided a suitable model for representing the structure of benzene. Nonetheless, his theory generated considerable criticism. The problem intrigued Teller and he used his expertise in spectroscopy to provide supportive evidence for Pauling's theory. In 1940, he and two associates published a paper in which they showed that Pauling's description of the benzene structure was meaningful (*37*). Sixty-eight years later, oblivious of Teller et al.'s paper, the Nobel laureate physicist Philip Anderson published similar evidence in support of Pauling's model (*38*).

Conclusion

We should not view the appearance of the Martians of Science separately from the societal and political situation in which they grew up and started their careers. This is why it is unlikely that a similar group of so outstanding scientists would emerge from a small geographical area and narrow layer of society and become as active in defense matters as the Martians any time soon.

Among the lessons that might be learned from the Martians' story is the advantages of open society, such as Western Europe and North America that can greatly benefit from the influx of mostly young people who are eager to fulfill their potentials. What Eugene P. Wigner noted is as valid as it was then, "Emigration is in many ways very stimulating. … In a foreign country you have to excel (*39*)."

It was characteristic of their time that it was more secure to start their careers in chemistry rather than in physics and mathematics. Although the Martians reached the peaks in their research careers elsewhere, their early encounters with chemistry proved fruitful in their later activities. Their fame is not due primarily to what they accomplished in chemistry; but there is no reason to ignore their performance in our field either.

Speaking about the Martians as characters, we need to add that all were rather peculiar. It was characteristic what the Dutch−American physicist and science historian Abraham Pais said, "…I have not been able to grasp the personalities not only of Wigner but also of Szilard and Teller (*40*)."

Acknowledgments

We are grateful to Gary D. Patterson (Carnegie Mellon University, Pittsburgh) and Seth C. Rasmussen (North Dakota State University, Fargo) for the invitation to be part of the Symposium they organized and the volume they compiled, and to Dr. Patterson for his critical reading of this manuscript.

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Chapter 11

George Rosenkranz: A Full-Range "Chemical Character"

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A dictionary definition of "character" usually cites quite a range of traits. George Rosenkranz, associated with the production of The Pill from Mexican yams, is, indeed, a full-range character: An excellent, enterprising high-school student who fretted that he would be accepted into the leading university in Hungary or Germany; a university student who supported his studies with unusual, non-chemistry employment and moved rewardingly among the international diplomatic set; a gifted organic chemist and an unorthodox research administrator; an impulsive romancer; a world-class bridge champion. This paper is based on an oral history interview of Rosenkranz conducted by the author in 1997 for the Chemical Heritage Foundation.

This chapter differs in two significant ways from all the others in this symposium volume: It is about a chemist, George Rosenkranz (Figure 1), who, so far as I know, is still making history, and it depends solely on his comments on his career to me during an oral history interview that I conducted and recorded for the Chemical Heritage Foundation in 1997 (*1*, *2*). His 96th birthday (August 21, 2012) was the day before the symposium.

In the sense of the symposium title, "chemical character" implies certain attributes. The following are likely: unexpected behavior, venturesome, unusually talented and resourceful, impulsive, swaggeringly confident, unconventional, memorable impression. George Rosenkranz, retired director of Syntex in Mexico City, is, I believe, a full-range "chemical character." Several years ago, when

In Characters in Chemistry: A Celebration of the Humanity of Chemistry; Patterson, G., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

I had the unusual pleasure of that oral history interview with him, he certainly made a memorable impression on me. In order to fill in some of the "character" characteristics revealed in that interview, I shall use exact quotes from it to give the true flavor of the oral history. Several of the "character" characteristics showed up early. Born in Budapest, Hungary, in 1916, George Rosenkranz graduated from high school in 1933. Like many high school graduates today, he worried about acceptance into the university, but in quite a different way. "My nightmare was that I would be accepted at the Hungarian university…the political situation was such that I didn't want to remain in Hungary." His family was Jewish, and regulations limited the university's enrollment to 10% Jewish. "I was afraid that with my good grades, I would be admitted. My parents insisted that I apply, but I wanted to get away…I was a good scholar, and I was awarded a fellowship to study chemistry at a [Berlin] university with one of the best faculties in this field. As I feared, I was accepted in Budapest…I pestered my parents so much that they finally let me apply to the ETH (*3*) in Zurich. Before being accepted there, I had to take an examination in spatial geometry, which we were not taught at the German School. I passed and moved to Switzerland in 1933. That's when I learned Schweizerdeutsch, which is probably the only language in which I do not have an accent…I always loved languages and speak six. I grew up with Hungarian and German, learned French at eight, English at ten. Later I picked up Italian and Spanish. I stayed for eight years in Zurich attending the university, the normal process in those days."

Figure 1. George Rosenkranz at Chemical Heritage Foundation, Winthrop−Sears Medal, 2004. (Courtesy of Chemical Heritage Foundation Collections).

He had some entertaining, revealing recollections of his academic experiences at ETH, one involving an early oral examination administered by the esteemed Professor Leopold Ruzicka. “This exam usually took around half an hour. Ruzicka pulled out Paul Karrer’s *Lehrbuch der Organische Chemie*, which was the bible of organic chemistry in those days. ‘In the Karrer, there are six errors. Name three of them’ he said. I had read the book, and I could name three errors. ‘Okay, but let’s see what else you know. Can you give me the synthesis of Vitamin B1?’ This was completely new then, but I had read the recent publication. I wrote the synthesis of the blackboard. ‘B2.’ I wrote the synthesis for that one, too. He opened the Karrer book to the index, found the letter D, and began questioning me about the listed topics. He continued to the letter E, grilling me. Time passed. I’d been with Ruzicka one-and-one-half hours and was sure I had blown it when he arrived at F. I remember it as if it were today. He asked, ‘What is formose?’ [I responded,] ‘Formose is a polymer of formaldehyde and a synthetic sugar, but if you write it with an a at the end, it’s a peninsular in the Japanese Sea.’ He looked at me and started grinning. He asked, ‘What are your future plans?’ ‘Herr Professor, I was hoping to do my doctoral thesis with you, but now that I have blown it, I don’t know what I am going to do.’ He replied, ‘Okay, you can start working for me on Monday.’ That was it. ‘But Herr Professor, I haven’t finished my synthesis.’ ‘Oh, that. Forget about it. You don’t have to finish the synthesis.’ So I am the only person in ETH history who got a degree for his work in organic chemistry without having to finish his diplomarbeit (*4*).”

While Rosenkranz was in Zurich, the changing political situation back home made it impossible for his parents to send him any money. He supported himself by capitalizing on other talents: by coaching a table-tennis team in a small town (in Hungary he had been the junior table-tennis champion), by performing with a theatre troupe in the evenings and selling his free tickets—members of the troupe were not paid directly—and by teaching other persons to play bridge, which he had learned to play very well while he was a child in Hungary. Some of his bridge students were in the higher echelon of Swiss society. One was the wife of the consul of Ecuador, who, learning that Rosenkranz wanted to leave Europe, encouraged him to go to Ecuador to teach chemistry. She talked to her husband, and Rosencrantz got his visa.

In 1941, he travelled from Zurich through Germany, Nazi-occupied France, and into Spain. From Bilbao he sailed on a ship bound for Cuba, where he was to change to another ship to Ecuador. On the three-week voyage, he learned some Spanish. While he was in Havana, waiting for the other ship, Pearl Harbor was attacked, and he didn’t get to Ecuador. The president of Cuba decreed that all refugees could remain in Cuba, essentially as citizens except without the vote. Rosencrantz chose to stay, sought employment at the university, but was rejected.

With swaggering confidence, he did get a job with Laboratorios Vieta-Plascenia, the largest pharmaceutical firm in Cuba, in spite of the director’s initial disinterest. “[The director] said, ‘for 15 years I haven’t had a single chemist in my organization. Why should I hire one now?’ I replied, ‘You’re telling me that you don’t need a chemist. I am telling you that you need a chemist. Well, give me a chance and I’ll show you.’ Luckily, he liked me and I started to work for him for the glorious salary of $25 per week.”

Rosencrantz's first assignment was to produce a compound for treatment of venereal disease. He decided on a bismuth salt (*5*), which he synthesized, and it was tested on patients at the hospital where his employer was director. "The product turned out to be fantastic…after a couple of months, my salary rose to $1500 per month. I also began to receive 15% of the profits on the products I developed."

He could be impulsive. Early on in Havana he went to a dance one night, saw an attractive woman there, asked her to dance, and at the end of the first dance asked her to marry him. She put him off for three years, until he received an irresistible offer from Syntex, a chemical plant in Mexico City, and told her he was going to go and wanted her to go with him. When I interviewed him in New York City 52 years later, she was still with him and, breezing in from shopping on 5th Avenue, joined us for lunch.

Versatilely talented, he was in New York to participate in a bridge competition/ convention. He is author of 14 books on playing bridge (*6*) and is the national champion of Mexico several times over.

At Syntex he was first scientific director, later president, chairman of the board, and CEO. He hired and motivated a team of high-achievers. While he was in charge, Syntex scooped all competing companies around the world by producing the birth-control pill from Mexican yams as starting material (*7*). When he started work with Syntex in 1945, the company was $300,000 in the red. In 1995 it was sold to Roche for $5.3 billion.

Near the end of the interview Rosencrantz gave an interesting personal perspective on his career, emphasizing his unconventionality: "One thing…of which I am proud is that together with my colleagues, we advanced steroid chemistry in the 1950s by ten years, just by our publication policy. We had a very simple policy: patent and publish. By that we gave the stockholders what they were entitled to, and our researchers what they needed—publication and peer recognition. The other pharmaceutical companies…where secrecy is such an important thing…eventually were forced into this position of allowing their scientists to publish because if they didn't, there would have been a palace revolution by their own people. They would have pointed to us. 'Look at Syntex, all the research they are doing, and they are publishing. Here we are doing the same thing, and we have to keep it in our drawers.' They had to publish, and this was to the benefit of both the whole scientific community and the field of chemistry. I am proud of that achievement. Cortisone, The Pill, and other things that I did in my life were OK, but the human contribution that I made to the growth of science and Syntex were more important to me."

The interview with George Rosenkranz was the easiest one I ever conducted. Without much need for prompting questions from me, over a four-hour period, he told a genuinely impressive story in a charming manner. Unusually talented in a variety of ways; completely self-confident; a keen sense of humor; adventurous, even risky, in some of his choices; ambitious, assertive, entrepreneurial, yet gifted with admirable perspectives on personnel and achievements: George Rosenkranz, I believe, clearly qualifies as an enviable chemical character.

Acknowledgments

I am grateful to Arnold Thackray for the gift of the book cited in reference 2 and to Amanda Shields, Program Assistant and Image Archivist at the Chemical Heritage Foundation, for supplying the photograph of Rosenkranz used in this chapter.

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1. All of the facts and quotations are taken from a transcript of the oral history interview recorded in Rosenkranz's hotel room in New York on May17, 1997. An interviewee-amended transcript is archived at the Chemical Heritage Foundation (Philadelphia) as Oral History Transcript #0159.
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Chapter 12

Paul John Flory: Physical Chemist and Humanitarian

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Paul John Flory received the Nobel Prize in Chemistry in 1974 for his lifetime of seminal contributions to the understanding of polymer science. He rose from Midwestern roots to a figure of truly international renown. He progressed through an early industrial period, including DuPont, Esso, and Goodyear, to an academic career, including Cornell, Mellon Institute and Stanford. He also fought to free scientists and their families from oppression. Upon receiving the Nobel Prize, he redoubled his humanitarian efforts. He worked tirelessly to liberate imprisoned and embargoed scientists behind the Iron Curtain. In addition to being remembered as one of the finest physical chemists of the 20th century, he leaves behind a wealth of scientific colleagues and friends who shared his passion for scientific truth.

Introduction

Paul John Flory was one of the leading physical chemists of the 20th century and received the Nobel Prize for his work in polymer science in 1974 (*1*). While his life was filled with science, he also cared deeply about humanity and made many scientific friends. In addition, he worked tirelessly in the cause of promoting human rights for scientists all over the world. He was involved in many disputes with other scientists, but this paper will focus on his development as a physical chemist, his cultivation of a worldwide community of scientific friends, and the large group of grateful scientists and their families from other countries.

In Characters in Chemistry: A Celebration of the Humanity of Chemistry; Patterson, G., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

Paul Flory was born June 19, 1910 in Sterling, Illinois. His father, Ezra Younce Flory was a minister of the Church of the Brethren, and this Anabaptist heritage can be traced all the way back to the Huguenot community in Alsace, France in the 17th century. Joseph J. Flory, a progenitor of six generations, came to America in the early 18th century (*2*). Paul Flory had a deep moral sense and often took difficult stands in the face of considerable opposition. He attended Manchester College, a small Church of the Brethren school in Indiana, and graduated with a degree in Chemistry in 1931. He was especially influenced by the Professor of Chemistry, Carl W. Holl (1886-1961), who advised him to go to Ohio State for graduate school.

Flory's time at Ohio State was characterized by a boundless thirst for knowledge and understanding. His school notebooks are extant and reveal the depth of his thoughts, even at this stage (*3*). As was customary, he obtained a Master's degree before being admitted to candidacy for the doctorate. This broadening program was of great benefit for his career as a chemist. His thesis work on the photochemical kinetics of nitric oxide with Herrick L. Johnston was just the preparation he needed to address some of the most exciting issues in chemistry in the 1930s. His obvious talent was recognized by the faculty at Ohio State and he was offered a job at the Experimental Station of the DuPont Company in Wilmington, Delaware in 1934 (*4*).

Industrial Growth and Development

At DuPont, Paul Flory had the good fortune to be assigned to the group of Wallace Carothers (Figure 1), the synthetic and physical organic chemist from Harvard. They developed a special intellectual bond, and Flory proceeded to apply his theoretical knowledge of chemical kinetics to the calculation of the molecular weight distributions of various polymerizations. While much of Flory's work at DuPont was theoretical, he also contributed to the experimental effort and often was asked to write the internal reports (*4*). Flory was a meticulous writer, and later, when he was an academic, any student of his was subjected to "writer's school." He was infamous for reminding them that "easy reading requires hard writing." This world came to an end when Carothers committed suicide. After this, there was no one at DuPont who valued pure science in the way that Carothers and Flory did, and he decided to find an academic post. Flory went to the Basic Science Research Laboratory at the University of Cincinnati in 1938.

This theoretical idyll did not last long, as the United States prepared for war. Flory was recruited for the effort at the Standard Oil Development Company at Linden, New Jersey in 1940. He worked with John Rehner on the swelling of cross-linked rubber networks. He also developed the mean-field approach to polymer solutions known as the Flory−Huggins theory. Maurice L. Huggins (1897−1981) of Kodak Research Laboratories was not his direct collaborator and insisted on fully independent efforts. Huggins completely missed the point that the theory assumes a mean field and fails in dilute solution where there are large regions that contain no polymer between molecules.

Figure 1. Wallace Hume Carothers (1896−1937).

Flory's rapidly rising star was noticed by the Goodyear Tire and Rubber Company, and in 1943 he was recruited to lead the fundamental research effort in polymer science in Akron, Ohio. Flory was the visible face of the Goodyear Company at the Rubber Reserve scientific exchange meetings, usually held at Akron. Other key players at the table included Carl Marvel (1894−1988) from the University of Illinois, Peter Debye (1884−1966) from Cornell University, and William O. Baker (1915−2005) from Bell Laboratories. The scientists of the Rubber Reserve Table became lifelong friends. One of Flory's chief collaborators at Goodyear was Thomas G Fox (1921−1977) (G was his middle name) (Figure 3). Flory and Fox published many papers together and were the best of friends. T. G Fox will appear in this story again. Another key collaborator was John R. Schaefgen (1894−) (*5*). In his Chemical Heritage Foundation Oral history he said of Flory: "My teacher, my leader, my idol. We thought a lot of him. We thought at that time that he would be a Nobel Prize winner." After the war was over, the atmosphere at Goodyear changed, and not for the better. Flory is infamous for complaining that he grew tired of "casting synthetic pearls before real swine" (*6*)!

Flory on the World Stage

Paul Flory's chance to dance on an even bigger stage came when Peter Debye invited him to give the George Fisher Baker lectures at Cornell in 1948. Debye himself had been a Baker lecturer. Cornell was a physical chemist's heaven. In addition to Debye, Harold Scheraga, Franklin Long and John G. Kirkwood were there. Flory attracted Fox from Goodyear to join him as a postdoctoral fellow, and some of their best work is from the Cornell years. His collaboration with William Krigbaum (1922−1991) resulted in some of the best polymer science of all time. They applied classical statistical mechanics to the problems of the excluded volume in single polymer chains and to the second osmotic virial coefficient.

The Flory−Krigbaum potential of interaction between two polymer coils may not be quite right, but it was a major step forward in 1950! With the theoretical support of Kirkwood, Flory and his collaborators developed the theory of intrinsic viscosity that is still used today. One of these developed into a close friend, Leo Mandelkern (1922−2006) (Figure 2). The crowning event of the Cornell years was the publication of his Baker Lectures as *Principles of Polymer Chemistry* (*7*).

Flory's next foray was to the University of Manchester in England, the home of Geoffrey Gee (1910−1996) (Figure 4) and Geoffrey Allen (1928−). Flory made major advances in the statistical mechanics of both bulk polymers and polymer solutions and gels. He was now a recognized world leader in polymer science. While Hermann Staudinger had received the Nobel Prize for polymers in 1953, it was Flory that was acknowledged as the intellectual leader. Flory and Gee respected one another and they could effectively argue about scientific issues. They both had exquisite scientific taste, and were almost always correct.

In the mid-1950s, the Mellon Institute for Industrial Research in Pittsburgh, PA was undergoing changes and they were looking for a world renowned scientist with management experience to head the operation. The creative vision of Robert Kennedy Duncan was carried on by Edward Weidlein and many American corporations had industrial Fellowships there. They called Paul Flory to the post in 1956 (Figure 5) (*8*). Flory immediately realized that he needed a manager for the day-to-day operations. He asked Tom Fox to leave Rohm and Haas and come to the Mellon Institute. Fox stayed for the rest of his career at Mellon. Flory inherited a great group of scientists from the Edward Weidlein years, and recruited many more. The most famous polymer scientists from this era included Marshall Fixman, Bernard Coleman and Guy Berry. They joined Hershel Markovitz and Edward Casassa (*9*). Eventually, the attempt to establish the Mellon Institute as a stable entity in the new American economy failed and Flory moved on.

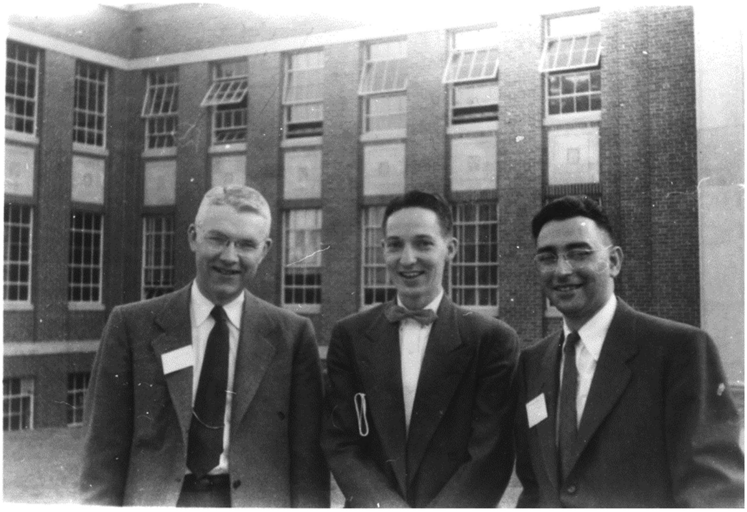
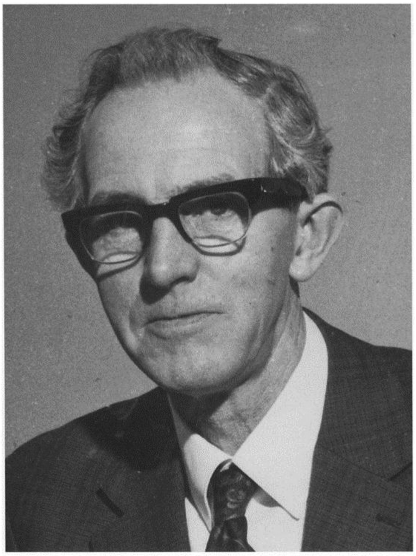


Figure 2. Paul Flory, William Krigbaum and Leo Mandelkern. (J.E. Mark, with permission).

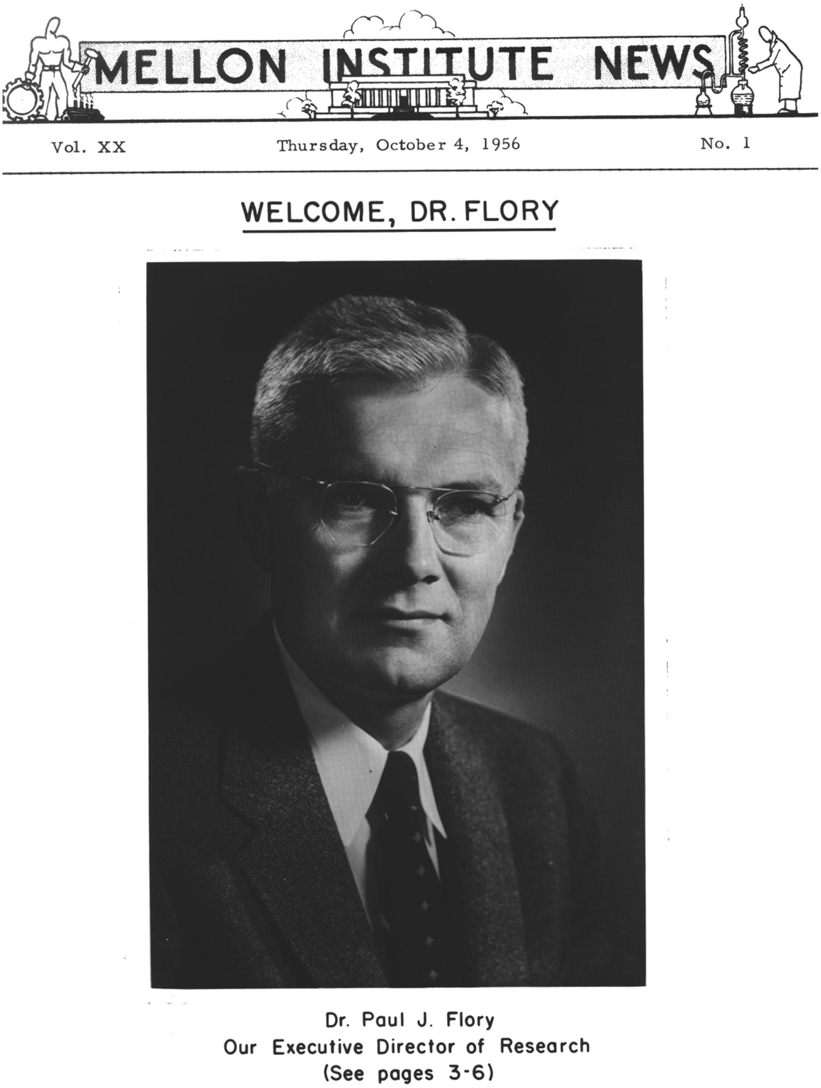
DR. THOMAS G. FOX

Figure 3. Thomas G Fox (1921−1977). (Mellon Institue Archives, by permission).



Geoffrey Gee

Figure 4. Geoffrey Gee FRS (1910−1996). (University of Manchester, by permission).



MELLON INSTITUTE NEWS

Vol. XX Thursday, October 4, 1956 No. 1

WELCOME, DR. FLORY

Dr. Paul J. Flory
Our Executive Director of Research
(See pages 3-6)

Figure 5. Paul John Flory (1910−1985). (Mellon Institute Archives, by permission).

The Stanford Years

In 1960 Stanford decided to renovate its chemistry department from a good regional group to a national powerhouse. They chose three men to build the new department: William S. Johnson, Henry Taube and Paul Flory. Stanford is now a world renowned department with Nobel Prize winners and the best graduate students.

Paul Flory established both a theoretical and an experimental program in polymer science. The theory of polymer mixtures was substantially improved and

Robert Orwoll and Bruce Eichinger made seminal thermodynamic measurements of polymer solutions over the full range of concentrations. The rotational isomeric state model, a theoretical approximation developed by M.V. Volkenstein, was applied to a wide range of conformational properties of polymers by Robert Jernigan and Akihiro Abe who became devoted disciples of Flory. The theory of rubber elasticity was improved and James Mark became the all-time Flory archbishop. He organized the complete works of Flory into three published volumes, and will be his biographer. The scientific production between 1960 and 1974 was prodigious and Flory finally received his Nobel Prize in 1974.

Rather than retiring to his magnificent homes in the Portola Valley and Big Sur, Paul Flory continued his hyperactive research program with postdoctoral fellows. Two of the most famous are Uli Suter of the ETH in Switzerland and Do Yoon, for many years at IBM, San Jose and now in Korea. Only death brought a close to Flory's scientific growth and productivity. He was working on many theoretical improvements right up to that point. One of my fondest memories involved a monumental theory of the full calculation of the light scattering structure factor for depolarized Rayleigh scattering from chain molecules (*10*). I had completed the theory, which involved matrices of order 147x147 and sent copies to Flory (Figure 6). He confirmed the derivation over the weekend and encouraged me to carry out the calculations at Bell Laboratories, where I went after Stanford. One weekend!

Flory as Humanitarian

While Paul Flory had been active in humanitarian causes for many years, his position as a Nobel Prize winner thrust him into the international limelight. William S. Johnson remembered his colleague and friend: "Paul was not the sort of person whose ego was inflated by receiving the Nobel Prize. Nevertheless, he was very pleased because the prominence and media interest that the Nobel laureate commanded afforded him the opportunity to be much more effective than before in his work on human rights issues" (*11*).

Flory was especially active in opposing human rights abuses in the USSR. He was a major player in the cause to free Sakharov, Orlov and Scharansky (*12*). He even offered to serve as a substitute hostage so that Yelena Bonner could go to the West for medical care. This effort, that involved more than 2000 scientists, was largely successful.

Paul Flory also opposed the restrictions on scientific travel imposed by the Soviets. In retaliation, he joined Herbert Morawetz and many others in organizing a boycott of the Tashkent IUPAC Meetings on Polymer Science in 1978. Only a few polymer scientists, such as Raymond F. Boyer, attended (*13*).

One of Flory's most personal activities was advocating for individual scientists or their families. He was able to reunite Virgil Percec, now at Cornell, with his wife and daughter, who were trapped behind the iron curtain in Romania (*14*). Flory also helped many individuals to emigrate to the United States. I shared a lunch table with five of them at an American Physical Society Meeting.

Paul Flory was frequently included on official humanitarian visitations of the United States State Department. He and his wife Emily were very active in support of the Women's Campaign for Soviet Jewry.

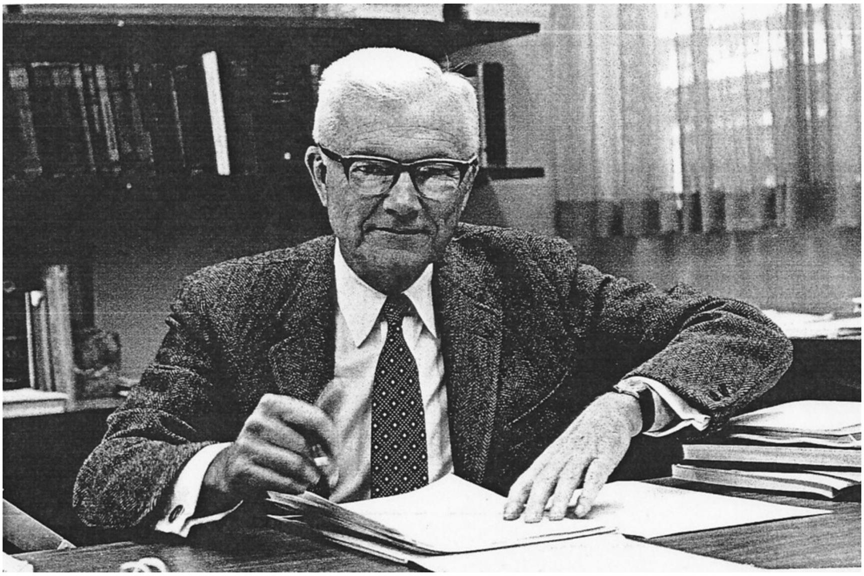


Figure 6. Paul Flory in his Stanford office, as I knew him.

Conclusion

Paul John Flory lived a scientific life where he sought new knowledge and understanding on a daily basis. He was never satisfied with his current level. This wholehearted devotion to science was recognized with the Nobel Prize in Chemistry in 1974. His commitment to scientific knowledge impressed all those who knew him well, and many of them caught the same "disease." He actively sought to collaborate with anyone who shared his commitment to scientific truth and made close friends with those who did. His legacy of friends matches his scientific reputation. He made everyone around him better. He was willing to risk his own life and reputation to support those who were persecuted and repressed. I miss him!

Acknowledgments

I would like to thank Andrew Mangravite of the Chemical Heritage Foundation for unpublished materials on the Tashkent IUPAC Conference. I would also like to thank Seth Rasmussen and Guy Berry for helpful comments.

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Editors' Biographies

Gary D. Patterson

Gary D. Patterson is Professor of Chemical Physics and Polymer Science at Carnegie Mellon University in Pittsburgh. He received his B.S. in Chemistry from Harvey Mudd College in 1968 and his Ph.D. in Physical Chemistry from Stanford University in 1972, under the direction of Prof. Paul J. Flory. He was a member of technical staff in the Chemical Physics Department at AT&T Bell Laboratories from 1972–1984. He received the National Academy of Sciences Award for Initiatives in Research in 1981 for his comprehensive studies of light scattering from bulk polymers. He has published more than 100 papers on the physical chemistry of amorphous media, many book chapters, and the monograph *Physical Chemistry of Macromolecules.* In 2003 he became a full-time historian of chemistry and was the 2004–2005 Charles Price Fellow at the Chemical Heritage Foundation. He is presently the Chief Bibliophile of the Bolton Society (the co-sponsor of this symposium), a member of the Boyle Society, and serves on the Heritage Council. He is the Historian of the Division of the History of Chemistry of the American Chemical Society and is the Chair-elect. He has published more than 20 papers and book chapters on the history of physical chemistry and polymer science, and the Springer Briefs volume *A Prehistory of Polymer Science*.

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