Science History: A Traveler's Guide

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Science History: A Traveler's Guide

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Foreword

The ACS Symposium Series was first published in 1974 to provide a mechanism for publishing symposia quickly in book form. The purpose of the series is to publish timely, comprehensive books developed from the ACS sponsored symposia based on current scientific research. Occasionally, books are developed from symposia sponsored by other organizations when the topic is of keen interest to the chemistry audience.

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

Editor's Biography

Mary Virginia Orna

Mary Virginia Orna, Professor of Chemistry at The College of New Rochelle, received a B.S. in Chemistry from Chestnut Hill College, and M.S. and Ph.D. degrees in Analytical Chemistry from Fordham University. Her research interests include pigment and dye analysis of archaelogical artifacts and, in particular, of medieval manuscripts. She is the author or editor of 14 books (including ACS Symposium Series volumes) and over a hundred encyclopedia, journal, and monograph articles. She is the recipient of numerous awards including a Fulbright Fellowship for Israel, the ACS George C. Pimentel Award in Chemical Education (1999) and the ACS Volunteer Service Award (2009). In 1990, in collaboration with John T. Stock of the University of Connecticut, she began conducting study tours for students as partial fulfillment of the requirements of a course in the history of science. These study tours expanded over the years to include adult learners; they also broadened their scope to include most of the venues described in this volume.

Chapter 1

Science History on the Road: An Overview

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While the present volume had its origins in a symposium held at the 237th National ACS Meeting in Salt Lake City, the content has been greatly expanded to include many additional sites. This introductory chapter outlines the rationale, goals and coverage of the book and includes some practical helpful information about its use.

Origins of the Volume

When Paul and Brenda Cohen began their book (*1*) with these words, "Why write a book on travel to places with scientific content?" and then proceeded to outline their reasons, this struck a chord in my wandering soul. For many years, I had been aware of their regular column in the *Journal of College Science Teaching* (*2*), and for perhaps just as long, I knew of John Wotiz's legendary "forced marches" across the face of Europe, Iron Curtain notwithstanding (*3*). And I, too, was a scientific traveler of a sort, having organized and taught for more than a decade an undergraduate course called "History of Science and Mathematics" that included a two-week travel component to England and Scotland in alternate years. During that decade, I became acquainted, through the good graces of John T. Stock (1911-2005), an ACS Division of the History of Chemistry colleague from the University of Connecticut (and a native Londoner), with many of the "movers and shakers" in the history of science, and particularly the history of chemistry, in the U.K.: Robert G. W. Anderson, former Director of the Royal Scottish Museum and of the British Museum; Peter J. T. Morris of the London Science Museum who knows scientific London like the back of his hand; and Frank A. J. L. James, prolific author and incomparable Faraday scholar at the Royal Institution.

In the late 1990s, as the popularity of my course waned among my undergraduate students, for a variety of reasons that included a decline in funding and changes in curriculum requirements, my tours to the U.K. gained adherents among faculty and other ACS colleagues from around the country. Word of mouth is a powerful communicator, and soon I had a mailing list of almost 100 potential and past participants who were eager to get out on the road but with a themed and structured program that provided intellectual stimulation – and not all of them were chemists or even scientists! So almost another decade passed when, in 2009, I decided it was time to "go public" and inform the ACS world of these tours which had, in the meantime, branched out to the European continent. Among the speakers that I had lined up for a symposium at the Salt Lake City ACS meeting in the spring of 2009 were a person who had participated in a John Wotiz tour, some who had participated in my own tours, some who had organized and participated in the Science History Tours run by Yvonne Twomey and Lee Marek, an Israeli, Zvi Koren, who proposed an archaeological study tour of Israel, and a "flight of fancy" tour to some almost improbable sites by Carmen Giunta, presently Editor of the *Bulletin for the History of Chemistry*. With such a stellar cast, it is no wonder that the ACS invited me to organize the talks into an ACS Symposium Series volume.

Goals for the Development of This Volume

So what is different about this volume? The Cohens's book is targeted scientific travel. It devotes at least one or 2 pages to over 250 scientific treasures in the United States, to sites as eclectically diverse as the National Museum of Roller Skating in Lincoln, NE and the Fermi National Accelerator Laboratory in Batavia, IL. Their criteria for including each site as a "treasure" were: the content and completeness of the collection had to be special, the site had to provide an educational component, and the presentation of the exhibits had to be beyond the ordinary. Could my Symposium Series volume live up to these expectations? The more I thought about it, the more I realized that this volume would have to be different, and yet complementary to the Cohens's goals.

First of all, my study tours had as one of its goals learning science through travel to sites where the science actually happened, a privilege available only since the latter part of the past century. Another goal was to describe how such travel can interface with the professional goals of chemists in academe, industry, and other areas of endeavor. In accomplishing these goals in detailing places of scientific interest throughout Europe, Israel, and other non-European venues, I realized that the book could provide its readers with the following insights:

Visits to places important in the history of science can provide teachers with interesting experiences to use in broadening their science curricula.

Emphasis on the chemistry background of each of the sites would be helpful to chemistry teachers and other chemists alike.

The scientific and technological developments of other cultures, the materials they used, the extent of international commerce in goods and crafts can impact on our own understanding of how science is taught and practiced in the USA.

Even vicarious visits to faraway places of scientific interest can enrich the homebound or those unable to travel.

It would be possible to plan a scientifically-oriented visit to a place not necessarily associated with science.

It would be possible to plan a scientifically-oriented visit to well-known scientific sites armed with information not necessarily available on the internet or in guidebooks.

Volume Outline and Content

While the book is broadly scientific and treats areas other than chemistry, where appropriate, chemistry is the highlighted science. The book is also organized on the "base city" principle whenever possible: certain cities are hubs from which the traveler can branch out to other venues of interest. This is certainly true of London, Paris, Stockholm, and to a certain extent Prague and Vienna. The first part of this book is an overview, first by way of this chapter, and secondly, by way of the incomparable narrative of a John Wotiz tour by Leigh Wilson. The second part of the book consists of four chapters on the sites in the British Isles: London and environs, including Oxford, the Royal Institution, Cambridge and Scotland. The third part of the book contains eight chapters on sites in continental Europe moving from north to south and then west to east. The final two chapters take us beyond European science to encompass the archaeology of Israel and fanciful journeys to far-flung Asia, Africa, and North and South America. The bibliography at the end of this chapter, while it concentrates on Europe, also includes references to sites in the United States and elsewhere.

The authors of the various chapters, including many already mentioned, have first-hand knowledge and in many instances, professional expertise, with respect to the history of the sites. Having lived in Rome for the past 5 years (which partially explains the delay in publishing this volume), I have visited the scientific venues in Italy many times and have also become an associate member of the History Section of the Italian Chemical Society. Marco Fontani, a colleague in the Italian Chemical Society and co-author of *The Lost Elements* (*4*), writes knowledgably and lovingly of science in Florence, the city of his birth. Leigh Wilson gives us a first-hand experience (Figure 1) of what it was like to travel on one of John Wotiz's legendary forays into the Communist bloc, complete with tales of aggressive guard dogs (and guards)!

Gary Patterson, Chief Bibliophile of the Bolton Society, treats us to some of the treasures to be found at the Fitzwilliam and Whipple Museums in Cambridge. Jan Hayes, Roger Rea, and David Katz delight us with their insights into the scientific joys of southern Germany, Eastern Europe, and Copenhagen, respectively. Roland Adunka, Founding Director of the Auer von Welsbach Museum, beckons us to the wonderful little town of Althofen where one can enjoy Alpine views, medieval castles and cathedrals, and unique industrial sites along with a visit to his museum, which documents the incredible accomplishments of the nobleman and chemist who laid claim to discovering four elements. Jim and Jenny Marshall take us on a rollicking adventure through Sweden, Finland,

and Norway (and a smidgen of Germany) to seemingly inaccessible sites, some marked with only a mailbox, in their search for the original mines and laboratories where many of 30-some-odd elements were discovered. Hang onto your seats as we take off – you are in for a special treat!

Figure 1. Travelers in the 1985 Southern Illinois University History of Chemistry Tour. John Wotiz is in the third row slightly to the left of center. Photograph courtesy of Larry Westmoreland.

Practical Information

Here is some practical information on what you may find in some of the chapters or venues:

Navigation Using GPS (Global Positioning System). When Selective Availability was discontinued by President Bill Clinton in the year 2000, high resolution GPS became available to the general public (20 meters). This has resulted in the proliferation of commercial dedicated GPS receivers, now routinely used by travelers and hikers. Persons who visit Europe may generally use their pre-set dedicated GPS units in Europe -- either automobile or hand-held -- if they procure the European packages, available on the map shop of the pertinent website.

Sometimes more convenient are apps on smart phones. Perhaps the most popular app is Google Maps, a system that was launched in 2005 and has progressed through several improvements. A traveler usually can immediately use this app in Europe (sometimes, one must formally activate the "European plan" to save money).

In all of these systems, a legitimate address when entered into the GPS unit or smart phone, quickly brings up the location, and then navigation tools allow the traveler to follow the indicated route to the desired destination. Sometimes an address is not known, such as with rural areas and/or "off-road" locations. Here geographical coordinates (latitude/longitude) must be used to identify the location, and most systems -- either dedicated GPS units or smart phone Google Maps -- allow this. Depending on which electronic unit is used, the format may be important. In general, the "plus-minus" format is always recognized -- that is, "+" is used for north latitude and east longitude, while "-" is used for south latitude and west longitude. Some systems -- notably Google Maps -- will also recognize "N,S", "E,W" format. As an example, the location of the Washington D.C. ACS office -- 1155 Sixteenth Street, NW: Washington, DC 20036 -- has the coordinates of +38.9055, -77.0361 (N38.9055, W77.0361). (The resolution is given here to 0.0001, which translates to 11 meters or less.)

There are three different formats for the coordinates: decimal degrees, degrees-decimal minutes, or degrees-minutes-seconds. Some systems, including Google Maps, will accept any of these. The decimal degrees format is becoming increasingly popular, and is used throughout this volume with one or two exceptions. (The ACS office location above is an example of decimal degrees.). In some instances degrees are given but both formats can be inserted into an appropriate website (*5*) for more information. Hand-held GPS units are universally available and might be necessary to locate some of the more remote locations.

Most email addresses and websites are given in the endnotes; take care to check these since they are ephemeral and often change.

In some instances, prices of admission are given; it is also well to check these on the internet before a visit. Some can be hefty indeed!

While Google maps are helpful, there is nothing like the *London A-Z* if you plan to follow Peter Morris around. I would also suggest obtaining a *Paris-par-arrondissement* book if you plan to hoof it around the Curie-Pasteur- etc. sites. There is nothing like a good, detailed, up-to-date map.

Email addresses are provided by each of the authors. Please feel free to check with them before you go.

While some of the places to visit are accessible only by car, the vast majority can be reached by public transportation. Please be aware that some countries place an age limit on drivers in terms of automobile rental, regardless of an impeccable driving record.

Countries outside the United States have attempted to make many venues accessible to physically challenged persons, but we have found that many are still not wheelchair-accessible or, by necessity, have many stairs but no elevators since they are historic buildings. Check first before you go. Also, street surfaces are often rough or cobblestoned, so be careful!

Here are some universal rules of travel gleaned from John Wotiz's group: Herb's Observation: Generally the best way to see a city is to get lost; Esther's Proverb: If you didn't want surprises, you shouldn't have come; Fran's First Law: If you can't carry it up six flights of stairs, don't bring it.

Acknowledgments

Profound thanks, first of all, to each the wonderful authors who lent their expertise to the development of this volume. Thanks, too, to all those who made suggestions, provided contact information, reviewed chapters, provided figures and photographs, and corrected our misconceptions and inaccuracies. A special debt of thanks goes to Istvan Hargittai, Ned Heindel, Raji Heyrovska and Michael Heyrovský, Attila Pavlath, Herbert T. (R.I.P. 2013) and Mary S. Pratt, Bro. Thomas Dominic Vance, and Larry Westmoreland. Special thanks to Jim Marshall for the material on GPS coordinates and expertly-crafted maps for many of our chapters, and to our excellent editors at ACS, Bob Hauserman and Tim Marney.

A note about our colorful cover is in order. Although some of the images will be familiar to the average reader, some are not immediately recognizable, although they are referred to or are characteristic of venues in the various chapters of the volume. The cover design is by Pamela Kame of the ACS Staff. The images (from left to right) are London: Big Ben; Paris: The Eiffel Tower; Saint Petersburg: Church of the Spilled Blood; Stockholm: Statue of J. J. Berzelius in Berzelii Parken; and Rome: The Colosseum.

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This is a partial list and does not include references scattered throughout this volume that are pertinent to the locations being discussed.

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UNESCO World Heritage Site
http://whc.unesco.org/en/list/
What can make this site a useful tool for science travel is the Search box near the top of the page. Enter your favorite science or technology: pottery, mining, metallurgy, wine, etc., and World Heritage Sites associated with the search term will be selected.

British Society for History of Science (BSHS) Travel Guide
http://www.bshs.org.uk/travel-guide/
This is an eclectic site that covers science in the broad sense of that word. However, it also highlights recent additions. One of them (2014) was labeled "Rosalind Franklin's Cambridge." It would be well to keep an eye on this site.

Laurence's Walks
http://www.laurenceswalks.co.uk/
Great stories of discovery, invention, and intelligence in London.

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Notes and References

1. Cohen, P. S.; Cohen, B. H. *America's Scientific Treasures: A Travel Companion*; American Chemical Society: Washington, D.C., 1998; p v.
2. Column title found in various issues: *Finding Science Past and Present*.
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Chapter 2

A View from the Cockpit: A Mid-Summer's "Flight" through Chemical Europe

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The summer-long flying trip through historically important chemical sites in Europe was a signature activity of the late John Wotiz, Professor of Chemistry at Southern Illinois University, Carbondale, IL. This chapter is an attempt to reproduce the unique atmosphere of this legendary scientific adventure.

Editor's Note

Undaunted by the problems presented by the Eastern Bloc, John and his five automobile convoy, with four persons in each car, proceeded to make even Julius Caesar's forced marches look like a picnic. Stopping at each site in a precisely timed itinerary, the group would meet with a personage, a knowledgeable guide, or a decendent of the pertinent chemist being highlighted or discussed. Able to draw on his vast experience in European venues, his many personal contacts, and himself as an able polyglot, only John could have woven together such a comprehensive tour to the "primary sources," namely, persons who could speak and lecture firsthand about chemical discoveries at each site, and all this prior to the advent of the internet and email! Following a brief biography of John by his dear friend, Ned Heindel, participant Leigh Wilson, drawing on the notes of another participant, documents the 1985 tour. Since the tour is so comprehensive, it is impossible to include city maps of each site. Therefore, a good map of Europe is recommended for reference while reading this chapter, and reference to internet sites, when provided, will be very helpful for the particulars of the tour.

In Science History: A Traveler's Guide; Orna;

A Brief Biography of John H. Wotiz
by Ned Heindel (Lehigh University)

John Henry Wotiz (1919-2001) was an internationalist, widely read and traveled; he was fluent in German and Czech and also read several other European languages. Born in Ostrava, Czechoslovakia (now part of the Czech Republic), John began his studies in chemical engineering at the Czech Polytechnicum in Prague. Due to the rising threat of Nazi invasion he came to the U.S. as an international student at Furman University in Greenville, SC, from which he received his BS-chem in 1941. After completing an MS-chem at the University of Richmond (1943), John started a doctoral program in organic chemistry at Ohio State. His education was interrupted by two years of military service as a First Lieutenant in the U.S. Army Chemical Warfare Service during World War II as a consequence of which he obtained his U.S. citizenship. John finished his PhD (1948) at Ohio State and became Assistant Professor at the University of Pittsburgh. He left academia for five years as research director at Diamond Alkali. John had a productive industrial career with over 40 international and domestic patents on chloralkali and acetylene chemistry before returning to academia as Chairman of the Department of Chemistry, Marshall University, Huntington, WV. In 1967, he joined Southern Illinois University (SIU), Carbondale, as Chairman of the Chemistry and Biochemistry Department.

Under the joint sponsorship of the U.S. National Academy of Sciences and the U.S.S.R. Academy of Sciences, Wotiz made an extended study of chemical education in the Soviet Union in 1969. Later, he visited other Eastern European, Asian, and Pacific Rim countries to study their systems of chemical education. These global studies of comparative doctoral programs led to the development of exchange programs involving graduate students and faculty between SIU and many foreign universities, primarily in Eastern Europe, notable among them being the Technical University in his birthplace, Ostrava, Czech Republic.

John's extensive European contacts grew with the foreign student exchange program that he implemented and his personal travels and in 1971 through the Division of Continuing Education at SIU he created a foreign travel/study course on the major sites of chemical history in Europe. Between 1971 and 1990, John conducted 10 Chemical History Tours. Participants could obtain academic credit in "The Evolution of Modern Chemistry" by completion of required course work. In 1990, John retired from SIU but he continued to work on the foreign scholars exchange programs. For these achievements, he received an honorary Doctorate from the Technical University in Ostrava in 1998. In 1992 he received the Dexter Award from the American Chemical Society for his outstanding contributions to the history of chemistry and in that same year he was the recipient of the University Gold Medal from the Technical University in Ostrava.

John was most proud of the fact that he had been the proposer of a Center for the History of Chemistry, a project which grew out of the ACS Division of the History of Chemistry (HIST) into today's Chemical Heritage Foundation. John was a long-time member of the HIST division, served as its chair in 1980, and published his extensive research on the life of F. August Kekulé as *The Kekulé Riddle* (1993). John Wotiz, who died in an automobile accident in 2001, is remembered for many achievements including his publications on *A Directory of Chemistry Museums* and Chemistry History Tours of Europe (*1*, *2*).

The Tour Begins: From Paris to the Swiss Border (4−8 June 1985)

[This part of the tour will be telescoped to avoid repetition with material in Chapter 7.] After the 19 participants gathered with John on the evening of 4 June and received their "marching orders," they spent the next day at the *Institut de France* (*3*) where they were met Madame Marie-Louise Hemphill, a grandniece of Louis Pasteur (1822-1895), who said a few words about her famous great uncle. She then toured the group through the *Institut* where they had the opportunity to examine original manuscripts by André-Marie Ampère (1775-1836), Pasteur, and Antoine Laurent Lavoisier (1743-1794). In the afternoon, they visited the *Musée des Arts et Métiers* (which houses the collection of the *Conservatoire nationale des Arts et Métiers*) where they were guided through exhibits on alchemy, energy production, the history of transportation, and saw the actual instruments used by Lavoisier to overthrow the phlogiston theory and to propound the law of conservation of mass.

Thursday 6 June, the group spent the morning at the *Institut Curie* where, among other things, they saw and touched some of the laboratory clothing worn by Marie Curie and confirmed by Geiger counter that the front pockets of her smock were still especially radioactive, given that the half-life of radium is 1620 years. Four of the stronger members of the group got to lift the lead "safe" in which Marie transported the gram of radium with which she was gifted by President Warren G. Harding in 1921. In the afternoon they toured the *Institut Pasteur* where Louis Pasteur lived and worked for the last seven years of his life. A highlight of the tour was a visit to the basement crypt that houses Pasteur's tomb, covered with floor-to-ceiling mosaics depicting some of the spectacular events of his career: the solution to the great wine crisis of 1866, the pasteurization of milk, the discovery of the cause of rabies, and the resolution of a racemic mixture of sodium ammonium tartrate into its chiral salts.

On Friday 7 June after the designated drivers picked up five cars from the Peugeot factory, the group took off for southeastern France: the goal was the city of Dôle, Pasteur's birthplace, where on the next day, 8 June, they toured the house where he was born, learned of his ancestry, school days, and early life. Then followed a visit to Arbois, site of the Pasteur summer home, and finally a visit to Belfort, Madame Hemphill's summer home, where she regaled the group with a "simple" supper. After supper, the convoy departed for the Swiss border, and in a matter of 45 minutes, the group arrived in Basel.

Switzerland (9−10 June 1985)

This part of the tour will read like a participant's diary in order to give the flavor of a typical Wotiz whirlwind touring day. The times, in square brackets, will reflect the European 24-hour clock, and dates will be written European style: day/month/year.

Sunday, 9 June

[9.30] Much trading of participants between cars, as those of the Catholic faith go to St. Clara in Basel, while the Protestants go to a church whose name was not recorded.

[11.30] Left for a short sojourn into West Germany to see the *Rhinefall* (the Rhine Falls) in Schaffhausen as we pass through. {A bit smaller than Yosemite and Niagara Falls but beautiful in its own right.} The tourist area of Schaffhausen has an open Currency Exchange and we are advised to change several days' worth of USD for West German marks, as they will be essential in both Czechoslovakia and East Germany, before we return to West Germany itself. That makes three uses of our passports in one day − crossing the Swiss-German border both directions and once to change money.

[16.30] We visit the *Schwinger Pharmaceutical and Historical Museum* (Figure 1 is one of the museum's historical displays) for a tour conducted by Madame Lydia Mez, who gave us all the facts in her own very personal style and with great grace. The museum had many examples of "medical kits," within glass cases, some going back over 300 years. It was very interesting to see how medicine evolved. All but the most modern solutions and tinctures had of course long since dried out, leaving powdery or oily (sometimes badly blackened) residues. Bottles and vials of salves and creams had fared somewhat better although some were discolored or with crazed or cracked surfaces. Some of the true powders looked almost still usable; however, they were surely long past their "expiration dates." Most cases had one or two examples of doctors' bags: starting with heavy cloth bags, then sheepskin bags and finally the "modern," hinged top, black (leather) bag, showing how they evolved through time. There were also displays of the "tools of the trade," from scalpels and bone saws to leech bottles, and pliers for removing decayed teeth (the only option hundreds of years ago). Much later, hand drills and bits developed in early attempts at filling teeth. These gave way to foot-pedal operated drills and then water-power-drilled holes, to be filled used with "current" silver-mercury amalgams.

[17.45] We left for a buffet supper at the home of our hostess, Madame Mez, which turned out to be fantastic − meant for royalty. Madame Mez was the perfect hostess, and the preparation of the food and the table settings were beyond words."

Figure 1. An 18th Century Pharmacy Laboratory Reproduction – Basel Pharmacy Museum. Photograph courtesy of Marie Sherman.

Monday, 10 June

[8.20] After taking the cars to a local Peugeot dealer for oil changes, we drove directly to our morning tour.

[9.15] Arrival at Hoffmann-La Roche, founded in 1896 by Fritz Hoffmann-La Roche (*4*). (It is not two "merged" companies.) First, a short bus tour of the grounds, pointing out the major manufacturing, research and analysis areas, was given by Dr. Adolf Pestalozzi and Maurice Wagner. This was followed by a lecture and slideshow presentation by Dr. Al Fischli. He spoke of the company's major interests in pharmaceuticals, vitamins, drugs, and fine chemicals, along with research diagnostics, perfumes and flavorings, instruments and plant protection. In 1934, it became the first company to mass-produce synthetic vitamin C. A later involvement was with anti-rheumatics, ergot alkaloids {This author took ergotamine sulfate for his migraines for decades!}, vitamins, benzodiazepines, Librium, Valium, sulfonamides, and other medicines.

[12.00] A leisurely and multi-course sit-down lunch in the Executive Dining Room was provided by Hoffmann-La Roche, with an after-dinner cigar being presented to ladies and gentlemen alike as a bonus. (Unfortunately, the record at hand does not indicate whether any were actually smoked at the time by either group − the executives or us.)

[14.00] We left HLR and had bit of time to sightsee in Basel on the way back to the hotel.

[17.30] Dinner at the hotel followed by a group meeting and review of the tour thus far. We received instructions for the next day, anticipating our longest and most complicated drive thus far.

Italy (11−12 June)

On Tuesday, 11 June at 8.00, we left Basel for the Lake Como region of Italy, arriving in Lucerne (still in Switzerland) at 9.45. We visited the Lion Monument and the Glacial Gardens and after lunch left for Schwyz, the city, district and canton from which the name for the unified cantons of Switzerland evolved. We drove up into the beautiful Swiss Alps and through the Furka Pass and then down into Lugano, and thence through Chiasso, last town in Switzerland, into Cernobbio, Italy, to finally reach Lake Como. The lake is shaped like an upside-down 'Y' with the city of Como situated on the southwest leg of the lake. By getting lost, two cars managed to actually pass through an intersection that had a central island, upon which there was a metal sculpture consisting of a thick vertical rod with spaced-out, horizontal, hollow rings (like flat edged hula hoops) which was an obvious modernization of the alternating silver and copper coins which Alessandro Volta (1745-1827) used to make his first batteries. These cars stopped to get postcards of the scenery, but not necessarily Volta's "*pila*" (pee-lah) or "battery" sculpture. By 18.00, our convoy was driving north along the western edge of southern Lake Como. Rock walls with occasional openings on the far left led into private properties; a narrow, left-southbound lane to the near left and a foot-high, rock, retaining wall continuing down a 5 to 15 meter "drop" to the lake hemmed in the northbound lane. All eyes but the driver's were looking for any "sign" of the hotel. Arrival at the Albergo Caramazza was accomplished by turning into a narrow opening in the rock walls, into a small courtyard with a San Francisco cable car-like turntable. Stopping on the turntable, the travelers emptied their luggage off to the side, and then with no one in the car but the driver, two young men turned the table until the driver could back into the car park, the former stables under the hotel proper! After an elegant dinner in the hotel, we were pleased to find that the Italian wait-staff and bartender were more than happy to take our last Swiss francs in exchange for libations.

Wednesday, 12 June. After breakfast, the parking attendants not only pushed the cars across the turntables, but a younger lad stood across the road gesturing when it was safe to exit the courtyard as the driver is quite blind, unable to see the passing traffic. The convoy traveled south along the lake back to the city of Como, and just after a sharp right-hand bend in the road followed by a sharp left, ecco! (*voilà* in Italian), Thomas Jefferson's Monticello, just like on the US nickel, appeared. The *Tempio Voltiano* (Volta's Temple) is a bit smaller (with only two stories, and narrower), with the central portion of each being quite tall, topped by a large neo-classical dome (*5*). We then had a tour of the *Tempio Voltiano* (Figure 2) with Mr. Giordano Azzi, who only spoke Italian, so his remarks were translated by Dr. Pasquale Tucci, a physics professor from Milan. Mr. Azzi said that most of the original devices were destroyed by a fire during the "Centennial of the Battery" celebration in 1899. Electric lights were not yet common, so kerosene lanterns were in use. Outside tents were loaded with tables of equipment spread out for the large crowds and these items were destroyed. However, many of the papers and diagrams were still inside the building and thus were spared from the fire! The wall of the circular staircase up to the second floor displayed the newspaper clippings describing the conflagration.

An aside: John Wotiz called this "the Most Honest Museum in the World." The current displays have green "felt" backgrounds if the material or apparatus was – although perhaps not made by Volta's own hand – obtained from an early 1800's source. Non-original reproductions are on red "felt" backgrounds. Most museums aren't as honest about their displaying of "official reproductions."

The relationship between Volta and Luigi Galvani (1737-1798) was explained in the lecture (*6*). Volta's two major contributions were the discovery of the "electric pile" (battery) and the decomposition of water by electrolysis. (Lavoisier had produced water by combination of oxygen with hydrogen from other chemical sources, but had not been able to decompose water directly, having neither electricity nor the alkali metals which Faraday would later produce using Volta's batteries!) Galvani discovered that the "animal electricity" which caused a frog's leg to contract (twitch) was the same as the "chemical electricity" of static or batteries.

Figure 2. Como: Tempio Voltiano. Photograph Courtesy of Roger Rea.

Munich, Germany (14–15 June)

Friday, 14 June. By 9.00, the convoy was heading up the west side of Lake Como, with an eventual destination of Munich, Germany. We ascended by and cable car and viewed the *Zugspitze* (the tallest of the German alps at 2962 m) and stopped at *Schloß Neuschwanstein*, the Castle that inspired Walt Disney's first Cinderella Castle. Passing through Oberammergau and the magnificent Alps, we arrived in München (Munich) at 19.00, and after dinner we spent a bit of time in the nearby Hofbräuhaus. "*Noch ein glas, bitte!*" (Another glass (of beer), please!)

Saturday, 15 June was the day designated for a visit to the *Deutsches Museum*, the tour being led by Prof. Wotiz himself. In the Chemistry and Chemical Engineering sections, there were three replicated laboratories: an alchemist's lab of the late middle ages, then the laboratory of Lavoisier, with sub-displays on the work of Joseph Priestley (1733-1804) and Carl Wilhelm Scheele (1742-1786), who all worked with gases. Lastly, the group arrived at the laboratory of Justus von Liebig (1803-1873). Liebig, who will be discussed at length in a later section, was the first to insist that even "undergraduates" practice in the chemical laboratory, which was the first step to the rise of chemistry in Germany.

One fascinating thing in glass-enclosed alcoves along a hallway, was operational chemical reactions initiated by the visitor pushing appropriate buttons. John commented that keeping these "working" was quite a task. Even with twenty adults present, there were very young children running in from one direction playing "Whack-A-Mole" with the buttons and running out the other end. The mechanisms have to 'ignore' such mishandling. It was, by far, the largest museum visited by the group, and has been known for many years as the world's largest museum of science and technology (*7*). We were then left on their own to view display rooms full of: astronomy; agriculture; time keeping; weights and measures; mathematical instruments; energy; transportation; and musical instruments. Something for everyone! There was not enough time to inspect all six floors! Figure 3 is a panoramic view of the *Deutsches Museum*.

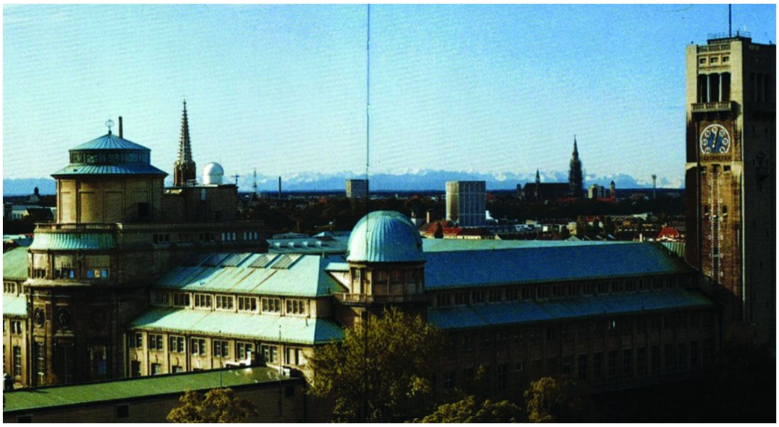

Figure 3. The Deutsches Museum. Photograph by Marie Sherman.

After an afternoon of Munich sightseeing, we met with Dr. Wotiz to plan the next day: a foray into the Eastern Bloc. John gave a short history of Czechoslovakia and information about the person awaiting the group there, Engineer Robert David. He was a high school friend of Prof. Wotiz. They were separated by WWII, when John left for the United States. They met and continued their friendship many years later when John visited Czechoslovakia again.

Crossing the Border into Czechoslovakia (16−18 June)

[The staccato pace of the tour is resumed as the group traverses the Eastern Bloc.]

Sunday, 16 June

[7.30] The cars were packed and we were off to Salzburg, Austria.

[9.00] Arrival in Salzburg for sightseeing.

[11.05] Departure from Salzburg.

[12.15] Passing through Linz, the convoy arrived for lunch at the last "western" truck stop in Freistadt, Austria and we filled our tanks with gasoline. "Check the oil!" said John. "Gas and petroleum products are much more expensive in the Eastern Bloc." We "checked out" of the West.

[13.00-13.15] No-Man's Land. We sat in our five cars in a row on a tarmac. We have left Austrian territory, but have not checked in through the Czechoslovakian "Customs Port of Entry." In order to get into Soviet Czechoslovakia on a group visa, John had to have "driver/owners." Each car was legally owned by its driver, as John couldn't enter Czechoslovakia as the owner of five cars! The "cohort" was on one group visa, so all five cars had to enter a heavily guarded parking area "inside Czechoslovakia." It seemed that multiple Americans owning cars and being on a group visa were not that common in the Soviet era, as John, in the lead car, had quite a lengthy conversation with the guards before all 5 cars were let in. One car (at random) was chosen to have everything emptied out of the trunk onto the tarmac and opened; much to the dismay of the lady whose "unmentionables" were laid bare to the assemblage. There were several "sniffer" dogs on leashes, controlled by armed guards, who were led around the open luggage and also allowed to sniff within the other cars' opened, but not emptied, trunks. The four other drivers were then told to accompany John into an "official building" with their owners' papers. These were passed to a clerk behind bullet-proof glass along with all passports, through a sliding double-long drawer system, as often seen in some American banks of earlier eras. After considerable perusal and some "official stamping," these were returned. Next John had to show the official his prepaid hotel vouchers for twenty people for three nights. He was then told how many Czech krona he would have to purchase (based on the number of people times the number of days to be spent in Czechoslovakia) with hard currency. This requirement was to prove the group's solvency (as well as to obtain hard currency for the Czech government!).

John got to sit at the one small table in the room as he got his currency out of his shin-money-guard. The room was dank and musty as well as dingy and gloomy despite it being a mid-summer's afternoon. The windows didn't appear to have been washed since the last rain, and there was just the one, traditional, low-wattage, east European 40 W light bulb, hanging down on its lonely wire casting scant light onto the table. By coincidence, the first solar-powered (no battery backup) calculator by SHARP had been released in 1979 and John was an early, proud adapter. He tried to calculate how much of the hard currency to give to the Czech clerk but the light was too dim for the calculator to function. So, there was John holding and aiming a battery-operated key-ring flashlight at the solar array on his calculator in order to make it work in that dingy light! Oh, how badly some participants wanted to take a picture of that scene, but they were sensibly deterred by the presence of a guard dog and three armed guards. Eventually, the appropriate amount of hard currency changed hands and without further ado, we were ushered back into our cars and out of the border station and on to our further Czech adventures after "only" an hour and a half at Customs.

[17.30] We arrived at the Kultúrny Dom Hotel (Home of Culture Hotel) in Příbram, Czechoslovakia, ČSSR. Příbram is a small town about 60 km southwest of Prague.

In the Soviet era, each city above a certain size, had a "Cultural Center" or "Home of Culture." This consisted of a hotel with attached restaurant, a café/coffee house/bar, and a "theater" which had 100 or so seats, a modest size stage for plays or concerts and a large roll-down movie screen.

A description of the hotel rooms is in order. They were designed much like a cabin on a cruise ship, but definitely less elegant. Each room was long and narrow. The entry door stopped against a small walled-in room (whose door opened outward into the room) containing a toilet and a small vanity sink. Next, a small, one-piece, wooden armoire, and twin beds, one against each wall. In between them, under a dust-covered window, a small utility/writing table with a small wooden chair. Next, along the other wall, one claw-foot, heavy, 1940's "master's smoking chair " with well-worn, faded fabric and the occasional hole or tear. Beside the chair, about five feet from the floor was a small wooden shelf with a black, Bakelite radio with an on/off switch and 5-6 buttons, but MINUS adjusting knob and frequency scale. (The group later learned that this arrangement was so guests could only listen to officially approved, pre-set radio stations.) Lastly, there was a small, three-sided plastic shower stall with a plastic, draw curtain.

[18.30] Having arrived in John's native country, two rounds of pre-dinner drinks were on him!

[19.00] Dinner was in the restaurant, with huge, hand-made dumplings.

[20.30] We had a meeting about the next day. After the meeting, some people went to the theater, which had a small jazz band in the orchestra pit and dancing on the stage, while others went to the coffee house/bar for live entertainment. Both groups reported friendly "locals" with Czech and American (English) songs enjoyed by all.

Monday, 17 June

[8.00] Robert David, John's friend, met the group for breakfast at the Hotel.

[9.00] We arrived at the *Příbram Mining Museum* (*Hornické muzeum Příbram*), one of the largest in Czechoslovakia (*8*). While there, we were outfitted with large, backless "slippers" worn over our shoes to protect, as well as to give the beautiful wooden floors a free "buffing," while visitors shuffle through the museum. There was a lecture in the museum on the history of mining in the area. The mnes were the most productive in Europe, producing huge amounts of gold and silver. By WWI, the area had some of the deepest mines in Europe (Figure 4). The word "dollar" originated from the Czech silver coin called the "thaler" (*9*).

Figure 4. Příbram Silver Mine. Photograph Courtesy of Larry Westmoreland.

Marie Curie got the pitchblende from which she and Pierre isolated radium from nearby Jáchymov (German: Joachimsthal). Tin was still mined in this area as late as 1985. A slide presentation was given by the town historian, V. Jesse, who was trying to preserve local history, mostly on his own. Mines and processing plants were stressed in his talk. Our group was then escorted around the mineral and geological exhibits and then took a short walk past various historical buildings to inspect a no longer active mine. It had elevators functioning down to the third or fourth level of a centuries-old mine shaft. It was an eerie experience since there were only a few working light bulbs hanging from the high ceilings.

[13.00] After lunch, it was a short drive to the *Antonín Dvořák Memorial Museum* at Vysoká (*10*). After a brief historical lecture about Dvořák (1841-1904), the group was treated to the playing of a very old (vinyl) record of a famous Czechoslovakian diva singing one of Dvořák's arias on what was purported to be his own, personal, hand-cranked, wooden Victrola.

Tuesday, 18 June

[7.45] After an early morning drive of about 45 minutes, Robert David met us at the Praha (Prague) Castle (*11*), Cathedral (*12*) and Museum complex (*13*). A Czech guide, speaking in English, gave us a tour of the Castle and then of the Cathedral, which took over 500 years to complete. It is very ornate, with towering, vaulted ceilings and beautiful stained-glass windows.

Since it was only about a ten-minute walk from Prague Castle, Robert also took the group to the *Strahov Library* (*14*), which the participants described as mind-shattering (Figure 5).

Figure 5. The Strahov Library Philosophical Hall. Photograph courtesy of Mary Virginia Orna.

It is part of one of the oldest Norbertine monasteries in the world, in continuous operation (except for persecutions) since 1143. Somehow the monks kept "kilometers" of books dusted and the floors polished, without having tourists wear slippers!

[12.00] The group crossed the famous Charles Bridge and spent the afternoon sightseeing the rest of Prague.

East Germany (19−22 June)

Wednesday, 19 June

[8.00] We left the hotel with Dresden, East Germany, as the ultimate goal for the day. The drive took us through Plzen, for whose brewery Pilsner beers are named.

[10.30] We made a stop in Karlovy-Vary, after which the U.S. city of Carlsbad and eventually the Carlsbad caverns were named. The Czech city, however, is known for its hot, artesian mineral springs around which fountains and entire buildings have been built. One "rents" a clay tea-sized cup with a pipe-like stem attached, through which one sips the "waters" of the various fountains. To offset the taste of the heavy mineral waters, young boys circulate selling chocolate-covered wafers, which "sold like hot cakes."

Our convoy stopped briefly at Jáchymov (Joachimsthal), the town from with Marie Curie bought the pitchblende (*15*) tailings (from its silver mines) which contained the radium that she and Pierre eventually isolated. On the outskirts of Jàchymov there is a town marker (*16*) which proudly displays a three-looped metal Bohr atom above the word JÁCHYMOV and the town shield.

[15.30] "Czeching" out was surprisingly easy, and NO dogs. We landed in no-man's-land at the multi-laned, very busy East German Border. There were dozens of cars and several buses. After two hours at the border, the group was finally allowed into East Germany after careful scrutiny of passports and car papers.

[19.30] Arrival at the beautiful, newly built Hotel Bellevue in Dresden, the ONLY hotel where Westerners were allowed to stay; they needed to pay off the mortgage after all.

Thursday, 20 June

[9.15] We left for the *Mathematics and Physical Science Pavilion* (*17*), part of the larger *Zwinger Museum* complex (*18*). The group was greeted by Mrs. Heidi Pasic, who was a very understanding and helpful guide to Dresden. Despite being forced to learn Russian after WWII, most of the professionals throughout East Germany spoke quite acceptable English.

The curator of the first floor, Dr. Girnus, showed us around "his" collection of globes of all sizes. The prize of this collection was a brass Celestial Globe from 1586. There were also collections of measuring devices and vacuum pumps. A tour of the second floor included collections of counting devices, clocks and watches. The guide loved his domain and his enthusiasm was catching. He explained that each morning he wound only about a quarter of the clocks and that they were deliberately kept a few minutes slow or fast, so that the hourly chimes didn't all ring at once.

[12.30] After lunch, we traveled to the Meissen Porcelain Works (*19*). The artisans of Meissen, in business since 1710, were the first Europeans to "discover" how to replicate the very expensive porcelain first created in China. Meissen is to china as Holland is to Delft. The self-guided tour (through windows, into brightly lit rooms) showed the mixing of the clay, the forming into plates and bowls and such, the overall glazing and the painting of the pattern or design, the firing and the cooled, final product. There was also a number of "museum cabinets" with antique pieces that survived the WWII bombings. Little else in and around Dresden did.

Friday, 21 June

[8.45] We departed for the Museum of Goldsmith Arts in *der Grünes Gewölbe* (the Green Vault) (*20*) which is part of the (meticulously restored) Dresden Castle, housing an impressive collection of artistic and historic treasures (Figure 6).

[9.45] Our group left for the small town of Grossbothen, where Nobel laureate (1909) Wilhelm Ostwald (1853 -1932) had his summer home, <u>*Haus Energie*</u> (House of Energy) (*21*). Guided by Mrs. Gretel Brauer, Ostwald's granddaughter, and Herr Wolfgang Girnus, a local Gymnasium (academic high school) instructor, we had a very detailed and well-organized presentation on Ostwald's contributions to equilibrium theory, catalysis and reaction kinetics. Ostwald started the *Journal of Physical Chemistry* with Jacobus Henricus van't Hoff in 1887. He also coined the word "mole," in 1894, as a quantity of chemical substance, even though the actual existence of "atoms and molecules" in the modern sense was NOT generally accepted by pre-1910 chemists (*22*). Ostwald also created a Color System which was in use for many years (*23*). He was a prolific writer and he retired from teaching in 1906 at the age of 53, having had his fill of it. He spent the remainder of his life at *Haus Energie* studying philosophy.

Figure 6. A pan balance: part of the treasure in the Museum of Goldsmith Arts. Photograph courtesy of Larry Westmoreland.

Mrs. Brauer then proceeded to give an account of Ostwald's life as seen by an elementary school student through the eyes of a young adult grand-daughter. She gave her account in German which was translated into English by Mrs. Pasic. Gretel was delighted to be giving her presentation to a group of science instructors who actually "got the science," rather than to the local school children. Gretel brought out some pieces of apparatus actually built and used by Ostwald, one of which was a water bath thermostat used to study reaction rates. It was ingeniously constructed in an era before bi-metallic strips and electric heating coils existed.

The group then went into the library to view the numerous books, papers and documents - including Ostwald's actual Nobel Prize − on display, continuing on to the family plot where Ostwald was buried.

During the course of the day, we learned that the East German Government was allowing Gretel to live in *Haus Energie* as the “caretaker” of the “Ostwald Museum.” During the Communist era, every Nobel Prize winner who could be even remotely dubbed “EAST German” was to be celebrated. Ostwald had been born in Riga, then officially Russian, but he became German in 1888 when the region was ceded to “Prussia.” In exchange for showing the public areas to the busloads of local school children, Gretel had a small apartment on the second floor, where she served a hearty buffet to the group.

[13.00] The story continued downstairs across the hall, in the Room of Colors, where several two- and three-dimensional representations of Ostwald’s color charts, all painted by himself, were displayed.

[17.15] We arrived in Leipzig with Gretel Brauer. A drive through the old town took the group to St. Thomas Church where Bach was buried.

[19:00] Our dinner was at the Hotel Merkur, Leipzig.

[21.00] Two members of the group drove Gretel Brauer back to Grossbothen. During the journey, they learned a great deal about how the East Germans managed their currencies with the “weak” East Mark, *Deutschmark* (which was “forbidden”) and scrip.

Saturday, 22 June

[8:30] We all went on a sightseeing tour of Leipzig, mainly to sites having connections to J. S. Bach and J. W. Goethe.

[11.45] After a quick lunch, the convoy left for the East/West border.

[14.30] We arrived at the East German border check-out point. There was a fair number of cars, including a few East German Trabant (*24*), that miracle of East German engineering with pasteboard sides and a motor about as powerful as the one in a western “riding lawn mower” − and at least as loud!

The East German Guards just seemed to have one pace − slow! Although all the trunks had to be opened, there were NO dogs and no search of actual luggage pieces.

[15.45] After a quick look at our passports by the West German Border guards, and one or two questions, the convoy passed into West Germany in under fifteen minutes.

[17.30] After arrival at the family-owned Wolf’s Hotel in Clausthal-Zellerfeld, West Germany, we acknowledged that there really was a certain psychological uneasiness to being Americans in Communist countries for about a week. So the participants did a large “group exhale” and let their hair down a bit.

Sunday, 23 June

[9.00] We had a free morning for church and lunch.

[14.00] The day’s lecturer, Herr Oberbergrat Dannert (Senior Mine Counsel), arrived at Wolf’s Hotel. He showed three short films on mining from 1923: the mining process (for silver, lead, and zinc), ore concentration, and smelting (with English “flash cards” embedded for comprehension). In Germany, everything was water-powered, unlike in Příbram, where everything was steam-powered. Crushers were used and then the ore was separated from “dirt” by hand. Some chemical analyses were done. The ore was first roasted to remove the sulfur and then it was smelted using alternating layers of coke and ore. The raw metal was then re-melted, separated from the slag, and poured into molds to make ingots (*25*). The local mine was a source of silver and lead for over 450 years.

[15.30] We then visited the *Oberharzer Bergwerksmuseum* (opened 1892) guided by Herr Dannert (*26*).

[19.30] After our return to the hotel, and dinner, we enjoyed a lecture by Levi Tansjo on the evolution of physical chemistry as it progressed; which was balanced by parallel advances in organic chemistry research. Wilhelm Ostwald coined the term "physical chemistry" in 1887 (*27*). He told his colleagues to have students do experiments and analyses (wet labs), rather than just "paper" chemical exercises (dry labs). The reaction of a mixture of formic acid and acetic acid with potassium hydroxide was explained. Mass action, solubility, cohesion and elasticity were also discussed, as was the theory of heterogeneous equilibrium. The beginnings of atomic theory and valence were also presented and related to two theories, those of Max Bergmann (*28*) and of Louis Berthollet (*29*). Dr. Tansjo also explained the terms exothermic and endothermic as they related to Hess' Law.

Monday, 24 June

[8.30] We departed for the museum in Sankt Andreasberg for a self-guided tour, where a reciprocating "man engine" ladder aided in the descent down into and especially the ascent out of the mine (*30*).

[13.00] We arrived in Göttingen, a city full of bicycles.

[15.00] After lunch and some unpacking, we drove to the local cemetery, the *Stadtfriedhof* (*31*), where there is a section in which there are EIGHT Chemistry and Physics Nobel laureates, each with an appropriately large headstone, as well as many other luminaries in the sciences (Figure 7)!

Figure 7. Walther Nernst, one of the luminaries entombed in the Göttingen Cemetery. Photograph courtesy of Larry Westmoreland.

Tuesday, 25 June

[9.00] We left for the chemistry museum at the University of Göttingen (*32*) and a lecture by Gunther Beer on Friedrich Wöhler (1800-1882), his teacher J. J. Berzelius (1779-1848), and his American students. Prof. Beer explained why the university was a magnet: excellent professors who believed in learning by research (uncommon in the late 19th century); not very expensive by European standards; open to all students; and very competitive, given its excellence in education.

[11.30] We had a tour of the Chemistry Museum before lunch; the university also houses many other museums (*33*).

[13.30] Our lecture on the history of geophysics in Göttingen since 1898 included the work of Carl Friedrich Gauss and Wilhelm Weber.

[14.30] We visited a display of the instruments used by Gauss, along with an explanation of their uses and operation in seismology.

[20.00] After dinner, John outlined the trip to Giessen on the morrow: to the *École Polytechnique* which Liebig brought with him from France; Liebig's initiative in agricultural chemistry even though he was primarily an analytical chemist; his invention of the potash bulb which allowed the first accurate analysis of potash; his invention of "NPK" (nitrogen, phosphorus and potassium) analysis; these are the numbers on modern fertilizers (*34*, *35*). Liebig also invented the fume exhaust hood and the water-cooled condenser: he was a very practical and innovative scientist. He advocated and practiced laboratory training for his students of chemistry, using small, wooden "openable windows" between his office and the lab rooms for close student observation! He also created a substance called "Liebig's Meat Extract" which was supposed to improve the health of young children whose parents couldn't afford to feed their youngsters proper servings of meat (*36*), somewhat similar to today's flavor-enhancing bouillon cubes.

Wednesday, 26 June

[8.30] We departed for Giessen, West Germany

[14.00] After lunch, we arrived at the Liebig Museum (*37*), (which is the actual building that housed Liebig's school). After viewing a video (*38*) which included a view of one of Liebig's "peepholes," there was a tour of the building and a lecture by Levi Tansjo. He spoke of the foundation of the *Journal of Physical Chemistry*, research work on the ionic strength of strong acids, and the experimental basis for the Law of Chemical Equilibrium that was based on the reaction of acetic acid with ethyl alcohol from work done by Marcellin Berthellot and Léon Péan de Saint Giles. The 19th century concept of affinities was also discussed.

[15.30] Wilhelm Lewicki, a sixth generation descendant of Liebig arrived with a family slideshow and many family anecdotes.

Thursday, 27 June

[8.00] The group packed up and left for Hoechst AG (Aktiengesellschaft: joint-stock company), south of Frankfurt (*39*).

[9.45] After our arrival and tram tour of the five square km, 30,000 employee campus, we stopped at a building housing an auditorium, café and smaller meeting rooms where there is a slideshow of the history of Hoechst, which began in 1863. Pictures of the pioneers of the company were shown; including one of the pharmacologist Emil von Behring (1854-1917) who received the first Nobel Prize in Medicine in 1901 (*40*). Hoechst started out producing dyestuffs but expanded into pharmaceuticals, plastics, and fibers. A lecture followed on various chemical compounds of a pharmaceutical nature, especially for fighting pain, starting with morphine, quinine, methadone, and other antitoxins.

[12.30] Our lunch was at Hoechst in an executive lunchroom (no cigars!).

[14.30] A tour of the Hoechst Museum, which houses first or early samples of some of their great dyestuffs and pharmaceuticals, followed lunch.

[16.00] We departed for Wiesbaden.

Friday, 28 June

[8.30] Leaving for Darmstadt, we drove through Mainz, stopping to tour the *Gutenberg Museum* (*41*), which was self-guided with signs in German and English.

[13.45] We arrived at the Kekulé Archives at the Technical University of Darmstadt (*42*). Friedrich August Kekulé (1829-1896) was born in Darmstadt; thus he is a "native son," so to speak, of TUD. We had a tour of the Archives with Suzanne Priebe who allowed the group to touch and (gently) hold his original manuscripts and publications! Suzanne was a gold mine of information about his early life and family.

[Editor's Note: Darmstadt is also the home of the GSI Helmholtz Centre for Heavy Ion Research where six elements were prepared: meitnerium (1982), hassium (1984), darmstadtium (1994), roentgenium (1994), bohrium (1996), and copernicium (1996).]

[15.00] Departure for Heidelberg followed our time at the TUD.

[16.45] Arriving at the Schloss (Castle), one of the most famous buildings in Europe (*43*), we took the self-tour through the *German Pharmacy Museum* which is a large part of the building. It includes a replica of a medieval apothecary as well as artifacts showing the evolution of laboratory instruments from the 16th through the 19th Centuries.

Saturday, 29 June

[9.00] We departed for the Chemistry Department of Heidelberg University (*44*, *45*).

[9.15] Arriving at the lobby of the lecture hall, we found that it was closed! John ad-libbed about the display on Robert Bunsen and his accomplishments. There were 58 known elements when Robert Bunsen and Gustav Kirchhoff discovered cesium (1860) and rubidium (1861) with their newly developed spectroscope and Bunsen's burner. Other chemists quickly followed their lead to discover thallium (1861), indium (1863), and helium (1868) spectroscopically. This multiplicity of discoveries allowed Mendeleev to create his 63 element Periodic Table of 1869.

[9.45] We took a walking tour of Heidelberg University with a running commentary by John, ending up at: [11.00] The Museum of Pharmacy in the "Castle" (*46*). The tour was conducted by Wolfgang Caesar, who did an excellent job as a guide, holding the group's attention for over two hours. It included the history of medicinals, pharmaceuticals, pharmacies, and medical instruments via the display of remaining accoutrements of over two centuries. We all agreed that it was a very fine museum in with respect to organization and "showiness" to the general public.

[13.30] We were then free for general sightseeing in (baroque style) Old Town Heidelberg where we passed a small plaza where a pensive Robert Bunsen (Figure 8) looked over at the building where he and Kirchhoff had worked (*47*). Our afternoon was followed by dinner and an evening concert.

Figure 8. Robert Bunsen. Photograph by Larry Westmoreland.

Sunday, 30 June

[14.20 pm] After a free morning, we left for Schwetzingen Castle with Wilhelm Lewicki for sightseeing and cakes and refreshments there (*48*).

[18.30] After dinner at the hotel, we said our good-byes to Wilhelm Lewicki and Wolfgang Caesar. We then attended an evening Bach concert in the town square.

Monday, 1 July

[8.30] We departed for the city of Odenthal, just east of Köln (Cologne) with sightseeing along the Rhine Valley, stopping at the Lorelei, and passing through Koblenz, one of Germany's oldest and most beautiful cities, situated at the *Deutsches Eck* (German Corner), where the Rhine and Moselle rivers converge.

[12:30] We enjoyed lunch and sightseeing in Bonn, the (then) capital of Post WWII West Germany, and famed as Beethoven's birthplace.

[17.15] We arrived at Oldenthal (*49*), and dined at the hotel.

[20.00] John gave a summary of some of the many methods used to discover new elements. These included: blowpipe reactions with carbon, electrolysis, flame colors, liquid air distillation, radioactivity, and particle accelerators.

Tuesday, 2 July

[9.00] We arrived at Bayer AG in Leverkusen where a history lecture followed by a site tour was given by Dr. Siegfried Kruger. Founded in 1863, the firm developed and produced many pharmaceuticals, rubber and plastic stocks, paints, textiles, dyestuffs, antiseptics, pesticides and fibers. Aspirin was developed in 1897-9 (*50*) but Germany lost its trademark after WWI as part of the Treaty of Versailles (*51*). The group saw a short film on current activities at Bayer (in English), followed by a tour of the display room which contained a scale model of the current Bayer plant in Leverkusen. There were 36,000 employees at the time of our visit. We then toured the pharmaceutical production display corridor, which looks down on the production and packaging areas, the automated storage and shipping area, the modern "Aspirin Plus C" production plant, the dyestuff mixing and packing plant and lastly, the on-site waste water purification plant, which empties treated water into the Rhine.

[14.00] We then enjoyed some sightseeing in Köln (Cologne), including the huge cathedral, followed by dinner.

Wednesday, 3 July

[9.15] We arrive at the *Röntgen Museum* (Figure 9) in Remscheid (*52*). An introduction to Wilhelm Conrad Röntgen's (1845-1923) background and his discovery of X-rays followed by a tour of the Museum was conducted by Herr Ernest Streller. Röntgen was actually born in this very building!

Röntgen did not actually discover X-rays first; that was done by Arthur Goodspeed and William Jennings at the University of Pennsylvania on 22 February 1890 (*53*). They did not, however, recognize the importance of their observations at that time. Röntgen, on 8 November 1895 independently discovered X-rays and succeeded in popularizing the taking of medical X-rays by X-raying his wife's hand a week after his discovery of these mysterious

“Rays.” This also resulted in his receiving the Nobel Prize for Physics in 1901, the first year it was given. Then followed a short film (in German with anecdotal comments on Röntgen, his discovery and the necessity for an appropriate “*kontrastmittel*” (contrast medium), i.e., the chemicals needed as components of the “X-ray film.” We then went on a conducted tour through the museum, which is the very building in which Röntgen was born. We got to see the actual X-ray of Frau Röntgen’s hand and her wedding ring. After lunch we went sightseeing in the Ruhr and Wupper Valleys.

Figure 9. Façade of the Röntgen Museum, Remscheid. Photograph courtesy of Larry Westmoreland.

Belgium and The Netherlands (4–9 July)

Thursday, 4 July

[8.30] All cars left in a caravan for Brussels for some sightseeing. They stopped in Aachen, which is the westernmost city in Germany. Although it has sulfur springs, the locals do NOT like the name “Bad Aachen,” because just “Aachen” puts them FIRST in any alphabetical listing of cities! A major site is the Coronation Church where Charlemagne became king in 768 following the death of his father. The Cathedral Treasury is regarded as one of the most important ecclesiastical treasuries in northern Europe, but much of it is only open to the public every seven years.

Friday, 5 July

The group visited the University Foundation (*Universitaire Stichting*, in Flemish) for a lecture on Belgian chemistry. Jan Baptist van Helmont (1580-1644) was an early professor at Louvain (Leuven) where his famous 5-year tree experiment was deemed to be the beginnings of quantitation. His student Jean Servais Stas (1813-1891) measured unusually accurate molecular weights and used 16 as the atomic weight of oxygen. Louis Melsen (1814-1886), acting as both chemist and physician, introduced tincture of iodine as a disinfectant. Other Belgian chemists, on the French side, were Joseph Louis Proust (1754-1826), who introduced the Law of Definite Proportions long before the discovery of molecules, and later, Jean Baptiste André Dumas (1800-1884), who invented a flask, now named after him, to obtain the relative molecular masses of volatile organic liquids. Presentations on alchemy and on the work of Ernest Solvay (1838-1922) in preparing soda ash rounded out the morning. In the afternoon, the group toured the Palace of the Academies.

Saturday,6 July

We spent the day at the "Museum of the History of Sciences" at the University of Ghent reviewing the life and career of Friedrich Kekulé since he had spent 9 years as a professor at Ghent before moving on to Bonn. Sightseeing in Zeebrugge and Oostende capped off the day.

Sunday, 7 July

Passing through Antwerp, Belgium, the group headed for Eindhoven, the Netherlands, arriving during the late morning. In the afternoon, the group toured the *Evoluon* Museum and Conference Center (*54*) which was opened in 1961 by Phillips Electronics (Figure 10). It seems like an amazingly "lifelike" looking UFO!

Monday, 8 July

The group left for Amsterdam, going through Utrecht for sightseeing and also with a side trip south of Haarlem for a flower show, arriving in Amsterdam at 15.30. Preparations were made for the overnight ferry to England the next day.

Tuesday, 9 July

[10.15] Arriving in Haarlem, we toured the *Teylers Museum* (*55*), the oldest museum in Europe, founded in 1784. The Oval Room contains the largest static electric generator in the world. It produces 500,000 volts and was once used to kill a cow for a local festival! It also contains books, manuscripts, and scientific instruments. The convoy then left for Leyden and the *Boerhaave Museum* (*56*) for a tour by Dr. Peter de Clercq. Some items of interest were original microscopes, the first of their kind, and some original Leyden jars and medical instruments. After a quick lunch, the group left for Zeebrugge and the overnight ferry to Hull, England.

Figure 10. Evoluon Museum and Conference Center, Eindhoven. Photograph courtesy of Larry Westmoreland.

England and Scotland (10–30 July)

Our convoy headed for Scotland giving nods along the way at Hull (A. G. V. Harcourt, founder of chemical kinetics), York Minster, and Eaglesfield (birthplace of John Dalton). At Glasgow University, we learned of the achievements of James Watt, Joseph Black, Thomas Graham, James Young, Frederick Soddy, and William Thompson, later Lord Kelvin. Heading north, they visited Saint Andrew's, the Haig Scotch distillery, and southward to Edinburgh and a visit to the Royal Scottish Museums, led by Robert G. W. Anderson, the then-Director. [Editor's Note: A chapter on Edinburgh (Chapter 3) by Robert Anderson is part of this volume.]

We proceeded further south to Newcastle (where the first "running" of the Nicolas-LeBlanc Soda Process took place), then to Manchester for a visit to the Museum of Science and Industry, the Salt Museum in Northwich and the Lion Salt Works (*57*) in nearby Marston. Next we visited the Halton Industrial Museum (*58*) which is now part of the Catalyst Science Discovery Centre located on Spike Island in Widnes, Cheshire (*59*). This is the only science center in the UK devoted entirely to chemistry. Then followed a visit to the Open University in Milton-Keynes with a side trip to the Jodrell Bank Centre for Astrophysics (*60*). [Editor's Note: The group then visited Cambridge, Oxford, and science sites in London proper, all to be described in detail in subsequent chapters in this volume.] The group also visited Stonehenge (in Wiltshire), and Bath, before leaving for Dover to take the hovercraft back to France. And while in France, prior to their air departure for the U.S., they also visited the International Bureau of Weights and Measures at Sèvres. Figure 11 is a "summary" of the tour!

Figure 11. The group not only navigated 11 countries, but also 10 currencies, depicted here! Photograph courtesy of Larry Westmoreland.

What Can Be Learned from a History of Chemistry Tour?

Participants in this tour learned how important it is to take good notes. They also learned that a study tour of this length (two months – non-stop) and magnitude (often 14-hour days) needs a great deal of processing over a long period of time. In the end, they all had a wealth of information about chemical history in virtually every part of Europe, except Russia and Scandinavia, that they could draw on in their teaching, historical research, augmentation of their books and artifact collections, and building of their photograph albums. Their look behind the Iron Curtain was privileged, incomparable, and unique, and never to be repeated. They also learned how important organization is in planning such a journey, and the caliber of the miracle worker who put it all together. They certainly earned their academic credit!

Editor's Postscript

According to his Chemical Heritage Foundation oral history (*61*), John Wotiz had originally conceived of his study tours for students; much to his surprise, his main clientele consisted of high school and college teachers interested in incorporating the history of chemistry into their teaching. Among the former, many of them took the course for credit to help them earn an advanced degree. Shorter versions of John's extensive tour continue today (e.g., the ChemSource Tours organized by the Editor, maryvirginiaorna@gmail.com). John attributes much of the success of the tours to his personal contacts, many of which were facilitated by another author in this volume, Robert G. W. Anderson, while he was Director of the British Museum.

Acknowledgments

To my Mother, who convinced a young, end-of-third-year chemistry teacher that it was, indeed, time to “See some Europe!”

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Chapter 3

Scientific Scotland

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It has generally been felt that Scotland "punches above its.weight" when it is judged by its rich scientific, technological and medical heritage. In European terms, it is a relatively small country, with a proportionately small population and a modest gross national product. It has frequently felt itself in contention with its larger and wealthier English neighbor. It was an independent nation, with its own monarchy, up until 1603, when under the 'Union of Crowns', the Scottish king, James VI, became King of Great Britain and Ireland, assuming the added title James I. It retained its own Parliament until 1707, when the Act of Union combined the countries into the United Kingdom, with England, Scotland and Wales being referred to as Great Britain. However, Scotland retained its own legal and educational system, and its own established church. The Scottish universities, once having a distinct pedagogic system, became more closely uniform with those in England from the middle of the 19th century.

Introduction

The development of science and medicine in Scotland was largely, though not entirely, based at its universities, while technology developed both within and outside the university system. Four of the Scottish universities are of ancient foundation: St. Andrews dates from 1411, Glasgow 1451, Aberdeen 1495 and Edinburgh 1583. There are now fifteen universities in Scotland, eleven of them receiving their royal charter from the 1960s onward (though several boast a somewhat earlier origin). It was not until the 1820s that England added new institutions to Oxford and Cambridge. These two even more ancient universities did not award degrees, post-Reformation, to any other than those who professed the Anglican faith, so the four Scottish universities were important in educating non-Conformists from throughout the British Isles (and beyond). It is probably fair to say that most of the earlier scientific development was centered on Scotland's two largest cities, Edinburgh and Glasgow (*1*).

Figure 1. Map of Scotland showing locations referred to in the text. Map created by James L. Marshall.

Transport: Getting There

Scotland is easily accessible from the south of Great Britain by good and frequent train services and travelers wishing to visit the main urban sites of Edinburgh, Glasgow and Aberdeen can find their way to the center of these cities by these means. Each of the three cities has an efficient airport and it is worth checking to find out whether there are direct scheduled flights from American and European cities.

St. Andrews no longer has a railway passing through, but it is easy to take a Dundee train from Edinburgh to Leuchars and catch a bus from the station to cover the last six miles. The sites mentioned within the main cities are all close to the center and buses and taxis abound. Cromarty (for Hugh Miller) can be reached by bus from Inverness; the journey takes about one hour. The town of Wick (for Alexander Bain) is remote, at the very north-east point of the Scottish mainland, but it can be reached by train directly from Edinburgh. Helensburgh is just a few miles to the west of Glasgow and there is frequent train service. The industrial sites described in the west of Scotland are remote and a car is the only practical form of transport.

Scottish towns and cities are fairly compact and their centers are best inspected on foot. The parking of cars is invariably frustrating.

Edinburgh

Much of the early development of chemistry has to be seen in the light of medical education. In many European cities, the earliest chemical activity can be considered to be pharmacy, which would have been based on, and controlled by, medieval guilds. This can be considered the case in Edinburgh, where the Incorporation of Barber-Surgeons was founded in 1505 (*2*). It was this body (whose name changed a number of times through its history, it now being called the Royal College of Surgeons of Edinburgh) which established perhaps the earliest institutional Scottish chemistry laboratory, in 1697. It is likely that the external structure of this building still exists, in High School Yards close to the Old College of the University: the laboratory would have been the basement of 'Old Surgeons' Hall,' (N55.9488 W03.1844) what is now, appropriately, the home of the University's Science, Technology and Innovation Studies Unit (Figure 2).

Figure 2. Old Surgeons Hall, High School Yards, Edinburgh. Ground Floor Chemistry Laboratory, 1697.

This part of Edinburgh is rich in scientific and medical associations, though most of the older buildings no longer exist. These would have included the original Royal Infirmary of 1729 and the Royal Medical Society of 1737. This latter was a student-run body and in 1776 it built a fine headquarters, constructed at rightangles to Surgeons' Hall (*3*). This was partly funded by donations from William Cullen (1710-1790), who had been professor of chemistry from 1756 to 1766, and his successor, Joseph Black (1728-1799), who held the chair from 1766 until his death (*4*). While on the subject of student societies, it is noteworthy that the first Chemical Society (perhaps in the world) was established by Black's students in 1785 (*5*). Its first records are kept in Edinburgh University Library.

The major University site is the Old College on South Bridge (N55.9475 W 03.1865) (*6*). It is a fine neo-classical courtyard building, originally designed by Robert Adam (1728-1792) but completed in the 1820s by William Playfair (1790-1857) (Figure 3).

Figure 3. Old College, South Bridge, Edinburgh. Façade originally designed by Robert Adam and completed in 1827.

It is accessible, externally, to all during the day. The earliest chemistry teaching took place on this site. Prior to the present building the 'Tounis College' been a jumble of medieval buildings, and Black's new chemistry teaching laboratory had to be squeezed into an area known as Printing House Square. From 2010, archaeological work revealed the site of a chemistry store, with unwanted apparatus and chemicals crushed under the demolished remains of a library. Black's successor, Thomas Charles Hope (1766-1844), helped in the design of a very large chemistry lecture theatre in the south-west corner of the quadrangle – it had to be large because, on occasion, Hope attracted more than 500 subscribers each year to his lectures. Black is mainly remembered for his work to identify the role of 'fixed air' (carbon dioxide) in alkalis, the first gas to be characterized chemically, in 1756. This was carried out in Edinburgh, though it is not known where. Black also developed the concept of latent heat, the work being carried out in Glasgow (see below). Hope was one of those who in 1793 claimed strontia to be the alkaline form of a new element (it was named after a Highland village where the mineral was found). Strontium was eventually produced as a metal in 1808 by Humphry Davy (1778-1829) at the Royal Institution in London.

To be exact, the chair held by Black and Hope was that of medicine *and* chemistry (*7*). The first holder of the chair was James Crawford (1682-1731), appointed 1713, but the real advance in chemical education at Edinburgh occurred in 1726, with the setting-up of the Medical Faculty. This would become a magnet for medical students from around the world. Benjamin Rush (1745-1813), first professor of chemistry at Pennsylvania College in 1768 and Benjamin Silliman (1779-1864), professor of chemistry at Yale from 1802, were both Edinburgh alumni. The greatest Scottish portrait painter of the late 18th and early 19th centuries was Sir Henry Raeburn (1756-1823), and in the south-east corner of the Old College is the Raeburn Room containing portraits of Edinburgh professors, including Black as a young professor, though this is the work of David Martin (1737-1797), John Robison (1739-1805), professor of natural philosophy from 1773 to 1805 – he had earlier succeeded Black as lecturer in chemistry at Glasgow, and John Playfair (1748-1819), also a professor of natural philosophy, who published on James Hutton's (1726-1797) geological theories). Admission to the Raeburn Room has to be applied for in advance.

Freely available, open seven days a week, is the Scottish National Portrait Gallery in Queen Street (N55.9533 W03.1883). Here will be found a number of portraits of Scottish scientists, including John Napier (1550-1617) of Merchiston, who in 1614 published a treatise on his discovery of logarithms; Sir William Thomson, Lord Kelvin (1824-1907), who was professor of natural philosophy at Glasgow and who worked on the Transatlantic cable; and Sir James Dewar (1842-1923), who developed the Dewar (or vacuum) flask, though at the Royal Institution. There are also fine portraits, commissioned from David Martin by the Royal Medical Society, of Joseph Black lecturing on fixed air, and of William Cullen. Henry Raeburn's 1778 portrait of the geologist James Hutton with rock samples is a magnificent early work. In the National Gallery of Scotland on The Mound (N55.9511 W03.1964) will be found an interesting 1887 bronze of Antoine-Laurent Lavoisier (1743-1794) deep in thought by Jules Dalou (1838-1902).

For three-dimensional material, a visit to the National Museum of Scotland in Chambers Street (N55.9468 W03.1904) is essential. It possesses one of the finest UK collections of scientific instruments, not all of them being Scottish. The earliest signed and dated astrolabe from Europe, Muhammad Ibn al-Saffar's (CE 1026/27) instrument which was constructed in Cordoba, Spain. There are early examples of 'Napier's Bones', a series of early (and more modern) microscopes, an example of William Herschel's (1738-1822) reflecting telescope, Charles Piazzi Smyth's (1819-1900) instruments for measuring the pyramids, Alexander Crum Brown's (1835-1922) strange pieces of three-dimensional knitting (*8*) – the list could go on and on. From a chemistry point of view, the highlight is undoubtedly the Playfair Collection, items from the University's chemistry laboratory passed to the Museum in 1858. This includes apparatus associated with Joseph Black, Thomas Charles Hope and William Gregory(1803-1858), who Lyon Playfair (1818-1898) succeeded in that year. An item known as Black's balance is particularly precious; even though it is not exactly a precision balance, it may have been used in the crucial quantitative experiments which led to the determination of fixed air. There is a quantity of green glassware, some of it large in size to make demonstrations visible from the back of the crowded lecture theatre (*9*) This was, in all probability, made in nearby Leith by Black's close friend Archibald Geddes (d. 1806), proprietor of the Edinburgh and Leith Glasshouse.

The National Museum continues to collect actively and there are more modern pieces on display, including part of a Cockcroft-Walton generator which was used in particle studies at the University. Occasionally displayed, and of great interest, are the Glasgow synchrotron and the immense Hydrogen-Helium Bubble Chamber, brought up from the Rutherford Laboratory in Oxfordshire. Technology is well represented as well. The main hall of the Museum has on display a massive statue of the steam-engine pioneer, James Watt (1736-1819), carved by Sir Francis Chantrey (1781-1841) and purchased by public subscription for Westminster Abbey where, in 1960, it was felt to be to occupy too much space. For all its weightiness, it has since led a peripatetic life (*10*). Oil and gas production from shales are currently prominent economic and political issues. It is of interest that the first shale oil samples in the UK were discovered by James 'Paraffin' Young (1811-1883) in Derbyshire, and later based on his exploratory work, an extractive industry developed from 1851 at Bathgate, a few miles from Edinburgh, which continued until 1962. Young's oil samples are preserved in the Museum. While there is not a systematic collection of medical history, there are some fascinating individual items. Sir Alexander Fleming's (1881-1955) 1945 Nobel Prize medal for the discovery of *penicillium* mold (leading to penicillin production) in 1929 is on show. An item in the collection which became very significant during World War II relates to the freeze-drying of blood plasma, a process developed from 1938. The original machine to achieve this at the Royal Infirmary of Edinburgh is in the Museum's collection. For those particularly interested in medical history, a visit to the Surgeons' Hall Museum of the Royal College of Surgeons of Edinburgh in Nicolson Street (N55.9467 W03.1842) is essential. Here can be seen anatomical preparations made at about the time that the University Medical Faculty came into being, in the mid-1720s.

Edinburgh University's science departments are now largely outside the center of the city, to the south at King's Buildings (N55.9240 W03.1762) (*11*). Chemistry was the first to move, in 1919. The architects were the firm of Rowand Anderson & Balfour Paul. The prominent entrance has been described as a " yawning Wrenaissance centerpiece" (*12*). The building has had a number of additions over the years and the complex is now known as the 'Joseph Black Building'. A plaque, celebrating Black's achievements and sponsored by the Royal Society of Chemistry, was affixed externally to the building on 4 December 2009. Inside is the Chemistry Museum, which includes a small but highly interesting group of objects connected with the various chemistry laboratories over the years. Included are Hope's samples of strontia and baryta, and Crum Brown's conjectural 1883 model of the sodium chloride lattice made out of knitting needles and balls of wool.

The Royal Society of Edinburgh was established in 1783 and has become recognized as Scotland's national academy for science and the humanities (*13*). Its home is at 22-24 George Street (N55.9531 W03.2014). Two Presidents in the 19th century were Sir David Brewster (1781-1868), whose work on optics led to the polarimeter, and William Thomson (Lord Kelvin), who determined the scale of temperature based on absolute zero. Portraits of both are found in the Society's rooms.

All over Edinburgh there are houses which have connections with great scientists, engineers and doctors (*14*). At 14 India Street there is a plaque to James Clerk Maxwell (1831-1879), born there in 1831 (N55.9553 W03.2055). He was a very great mathematical physicist whose achievement was the formulation of equations describing the electromagnetic field. His statue, unveiled in 2008, is at the east end of George Street (N55.9531 W03.2003) (Figure 4).

Figure 4. James Clerk Maxwell monument, George Street, Edinburgh. Sculpture by Alexander Stoddart, 2008.

Alexander Graham Bell (1847-1922), inventor of the telephone in Boston, USA, in 1875, was born at 16 South Charlotte Street (N55.9511 W03.2062).

There is a bronze plaque to Sir Arthur Conan Doyle (1859-1930) at 2 Picardy Place (N55.9568 W03.1875). He studied medicine in Edinburgh and worked as a military physician during the Boer War, but he is best remembered as being the creator of the detective, Sherlock Holmes. A good deal of chemistry is to be found in Conan Doyle's books (*15*).

One of the first women to study medicine at Edinburgh was Elsie Inglis (1864-1917). She set up a medical school for women, a maternity hospital staffed by women, and a hospice at 219 High Street (N55.9504 W03.1879), marked with a bronze plaque.

Joseph Lister (1827-1912), later Lord Lister, who is remembered for his work on antisepsis in hospitals, was a Londoner who worked as a resident house physician in Edinburgh before going to Glasgow as Regius Professor of Surgery. In 1869 he moved back to Edinburgh to be Professor of Clinical Surgery. His Edinburgh homes were at 11 Rutland Street (N55.9496 W03.2079) and 9 Charlotte Square (N55.9525 W03.2082), both now having inscriptions carved into the stone.

Sir Henry Littlejohn (1826-1914) was Edinburgh's first Medical Officer of Health, in 1862, and he tackled infectious diseases in the city, advocating compulsory inoculation against smallpox. There is a bronze plaque in his memory at 24 Royal Circus (N55.9574 W03.2054).

Sir James Young Simpson (1811-1870), discoverer of the anesthetic power of chloroform in 1847, lived at 52 Queen Street (N55.9541 W03.2030) (Figure 5). He was Queen Victoria's (1819-1901) Physician in Scotland and the Queen somewhat controversially took the anesthetic during the birth of Prince Leopold (1853-1884) in 1853.

Edinburgh itself has never been a major center of the chemical industry, though it was surrounded by coalfields, and from the middle of the 18th century there was a good deal of activity within twenty miles of the city: a major ironworks to the west at Carron (N56.0260 W03.7914), a sulfuric acid works to the east at Prestonpans (N55.9595 W02.9845), and across the Firth of Forth, the 9th Earl of Dundonald's (1748-1831) tar works at Culross (N56.0549 W03.6298) (*16*). Inside the city was a sal ammoniac plant, established in 1760 by the geologist James Hutton and his friend, John Davie, in Davie Street (N55.9452 W03.1830). One industry, established in 1820, survives, and that is a works for extracting and manufacturing alkaloid products. It is best known by its name from 1836: Duncan Flockhart & Co. (*17*). Its major product was lucucasium, an opium-substitute but from 1847, the company was commissioned by Sir James Young Simpson to manufacture chloroform. Its original location, at 52 North Bridge (N55.9504 W03.1878), is now occupied by the Balmoral Hotel. A plaque now records the site of the premises.

Finally for Edinburgh, and an up-to-date figure: Peter Higgs (b. 1929), whose connection with the University of Edinburgh dates back to 1954, won the Nobel Prize for physics in 2013 for describing the Higgs Boson. The Higgs Centre for Theoretical Physics has been established in the James Clerk Maxwell building in George Square (N55.9435 W03.1904).

Figure 5. James Young Simpson and friends having inhaled chloroform, possibly at 52 Queen Street, Edinburgh.

Glasgow

Glasgow can easily be reached by train from Edinburgh (and vice versa); the journey takes less than one hour. The University of Glasgow was originally situated in the High Street near the 13th century Saint Mungo's Cathedral. But in the mid-19th century, the land on which it was built was required as a marshalling yard for the railways and essentially nothing survives of the original university buildings. The University moved to Gilmorehill, a western inner suburb (N55.8721 W04.2882). The fine and striking buildings were designed by Sir George Gilbert Scott (1811-1878) from 1870 (Figure 6).

Science and medical teaching at Glasgow can be seen as developing energetically during the Scottish Enlightenment. In 1727, a chair in natural philosophy was established and held by Robert Dick (d. 1763), followed by a lectureship in chemistry in 1747, the first holder being William Cullen. In medicine, a professor, Robert Mayne (d. 1646), had been appointed in 1637 but there was no continuity until the post became established in 1714, when John Johnstoun took up the chair.

Strathclyde University, at Royal College, George Street (N55.8613 W04.2464), also has an honorable tradition in science and technology. Its origin can be traced to Anderson's Institution, established through the will of John Anderson (1726-1796), professor of natural philosophy at Glasgow University from 1757 to 1796 (*18*). The new institution, established in the year of Anderson's demise, was to encourage those less well-versed in mathematics to undertake science courses. The Department of Physics at Strathclyde possesses a fine collection of late 18th and early 19th century demonstration apparatus.

Figure 6. Glasgow University, buildings designed by George Gilbert Scott, completed 1870.

The most famous engineer associated with Glasgow was not an alumnus of any university. James Watt was employed as ‘Mathematical Instrument Maker to the University’ from 1757. It was six years later that he repaired the demonstration model Newcomen engine, now to be seen in the Hunterian Museum (N55.8717 W04.2885), which started his train of thought about improving the efficiency of steam engines (Figure 7). His early experiments were started in Scotland but his partnership with Matthew Boulton (1728-1809) and the large-scale manufacture of rotary engines started when he went to work in Birmingham in 1775.

The University’s Hunterian Art Gallery and Museum was originally established in a radical neo-classical building in 1807 to house the collection of the London-based anatomist, William Hunter (1718-1783). This Museum building was demolished ca 1880 when the railways moved in (*19*). The new Hunterian Museum now lies to the south side of University Avenue. It largely consists of a collection of natural history specimens but there are a few instruments, including Lord Lister’s microscope. The Department of Natural Philosophy (it retains this earlier title, not becoming ‘Physics’, as elsewhere) lies nearby and there is a distinguished collection of physical apparatus, most importantly items associated with Lord Kelvin (William Thomson) and with James Joule (1818-1889). Many of Kelvin’s instruments were constructed for him by the Glasgow company of James White, set up in 1849. This firm, which has passed through many name-changes, now operates as Kelvin Hughes Ltd, part of Smiths Group plc, with its factory in North London. In the Department there is Kelvin’s famous 1887 ‘artificial glacier,’ a seemingly non-ending flow of pitch down a mahogany slope. Kelvin is commemorated on the wall of the house he occupied from 1870 to 1899, 11 Professors Square (N55.8715 W04.2905) (Figure 8).

Figure 7. Workmen gazing at James Watt. Painting by William Stewart in Hunterian Museum, ca. 1880.

The chemist, Frederick Soddy (1877-1956), taught at Glasgow from 1904 to 1914. On the wall of 11 University Gardens (N55.8728 W04.2903), formerly a professor's house, there is a plaque commemorating Soddy, who worked on the transmutation of elements and who, in this house in 1913, coined the term *isotope*. Soddy won the Nobel Prize for Physics in 1921.

Figure 8. Professors Square, Glasgow, home of William Thomson, Lord Kelvin.

Aberdeen

For well over two centuries Aberdeen had two universities, the original 1495 foundation of King's College, and from 1593, Marischal College as well. They merged in 1860, but this has led to complexities in dealing with the early history of university education in the city. Natural philosophy was taught informally at both in the 17th century and both possessed small collections of apparatus. It was at Marischal College that Professor Patrick Copland (1748-1822) firmly established a Department of Natural Philosophy and a number of early instruments used by him during his tenure between 1775 and 1822 can usually be viewed in the foyer of the Fraser Noble Building of the current University (N57.1659 W02.1046).

When the colleges merged in 1860, the King's College professor, David Thomson (1817-1880), headed natural philosophy in the united University. He helped to equip the Cromwell Tower Observatory in the King's College quadrangle (N57.1650 W02.1003), which can be visited by special arrangement with the Department of Physics. There have been some outstanding professors of natural philosophy since then. James Clerk Maxwell, of the Maxwell Equations, held the chair from 1856 to 1860. He is commemorated by a plaque on his house at 129 Union Street (N57.1461 W02.0996). Sir George Paget Thomson (1892-1975), son of the discoverer of the electron Sir J. J. Thomson (1856-1940), won the 1937 Nobel Prize for physics for his work on the diffraction of electrons by crystals conducted at Aberdeen during the 1920s. The colorful Reginald Victor Jones (1911-1997), a pioneer in the development of radar during World War II, was professor from 1946 to 1981.

An unlikely pioneer of electric locomotives was Robert Davidson (1804-1894), whose workshop was in Canal Street (N57.1716 W02.1254). In 1842, his battery-powered locomotive, Galvani, ran at four-miles-per-hour on the Glasgow to Edinburgh railway track (the railway had not yet reached Aberdeen by that time).

St. Andrew's

The University of St. Andrews is situated in a delightful town of the same name, known also for its importance to the world of golfing. It has some interesting scientific associations, even if it never developed quite the same strengths as did Glasgow and Edinburgh. There are important collections of instruments. The Department of Physics on North Haugh (N56.3392 W02.8120) possesses items dating from the 16th century onwards, including an outstanding astrolabe constructed with Gemma Frisius' (1508-1555) universal projection. It was constructed by the earliest of the recorded English makers of astronomical and mathematical makers, Humfry Cole (d. 1591), in 1575. An armillary instrument by the same maker is dated 1582. There is also an improbable mariner's astrolabe by Elias Allen (1588-1653) of 1616, one of the instruments acquired by James Gregory (1638-1675) who described the optical system of the Gregorian telescope for the University Observatory in 1673.

Chemistry was taught at St. Andrews from 1811. A collection of glassware was probably purchased from Thomas Thomson (1773-1852) in that year, and some of it survives in the Department of Chemistry's Purdie Building (*20*). John Read (1884-1963), author of *Humour and Humanism in Chemistry* (*21*), taught at St. Andrews from 1923 to 1963. He was particularly interested in the history of alchemy, and through his efforts a significant collection of early manuscripts was built up. These are now in the University Library Special Collections on North Haugh.

St. Andrews has an excellent University Museum (MUSA) at 7a The Scores (N56.3425 W02.7937). There are displays on the kaleidoscope and the stereoscope, both invented by David Brewster, Principal of the University from 1838 to 1859.

Two pioneering photographers in Scotland have associations with the town. Robert Adamson (1821-1848), born there, produced his first calotype in 1841, only two years after W. H. Fox Talbot (1800-1877). He teamed up with David Octavius Hill (1802-1870) in 1843 (*22*). Their early productions are best seen at the Scottish National Portrait Gallery in Queen Street, Edinburgh. Adamson and his brother John encouraged Thomas Rodger (1832-1883), a graduate of St. Andrews and another early pioneer of photography.

Industry

There are many industrial sites related to chemical industries scattered around Scotland. Some are in remote places and are accessible only by those with cars. There were surges of activity in the 18th and 19th centuries, first with improvers seeking to increase yields from their lands, and later with Glasgow industrialists supplying huge quantities of machinery and locomotives to the Empire.

A great deal of mining activity was carried out in Scotland from medieval times onwards, mainly on quite a small scale. Practically no evidence of this survives on the ground today, but exceptionally, two evocative sites lie on remote moorland between the A76 and A74(M) roads in South Lanarkshire, Leadhills (N55.4185 W03.7600) and Wanlockhead (N55.3970 W.037770). Here, lead, copper, zinc and silver were mined, and some of the buildings associated with this activity do survive, including 18th century miners' libraries. A light railway runs on part of the mineral line track during summer months. Four evocative paintings of operations at Leadhills in the 1780s, by the artist David Allan (1744-1796), can be inspected at the Scottish National Portrait Gallery in Queen Street, Edinburgh (*23*).

Supplies of trees, a source of charcoal, lasted longer in Scotland than England, and there are several sites of iron smelting in the West Highlands. The best-preserved remains are the Bonawe iron works with its furnace, near Taynuilt (N56.4291 W05.2393), northwest of Glasgow. This operated from 1753 until 1876. The assemblage is admirably cared-for by Historic Scotland and can be visited during summer months (Figure 9).

A significantly more important and longer-lasting iron-producing site was the Carron Iron Works, near Falkirk (N56.0019 W03.7839) in the central belt (*24*). The blast furnaces, fuelled by coal, were established by John Roebuck (1718-1794), Samuel Garbett (1717-1803) and William Cadell (1708-1777), in 1759.

From 1796, a new form of cannon, the ‘Carronade’ was made in large numbers here to supply the Royal Navy in the Napoleonic Wars. From the 20th century, the company supplied the familiar red pillar-boxes for posting letters, and telephone boxes (*25*), designed in 1936 by Giles Gilbert Scott (1880-1960). Practically nothing remains of the earlier works today but a Victorian clock tower survives, with four Carronades and a fragment of the original blast furnace (Figure 10).

Figure 9. Bonawe iron furnace, Taynuilt, ca. 1753.

Figure 10. Carronades in the surviving clock tower of the Carron Works, Falkirk.

Also vanished are the remains of lead vessels which once must have existed for Roebuck's and Garbett's process for sulfuric acid (the lead chamber process), established from 1749. From 1784, Roebuck established a pottery alongside at the site. He died in July 1794 and he was buried in Carriden Old Churchyard near Bo'ness, on the Firth of Forth to the west of Edinburgh. Part of the inscription (in translation from Latin) reads: "He cultivated a number of recondite and abstruse sciences, among which were chemistry and metallurgy. These he expanded and adapted to human needs with a wonderful fertility of genius…"

Finally, in this very brief survey of industrial sites, the location of Archibald Cochrane, Earl of Dundonald's coal tar distillery works is known, very close to picturesque Culross Abbey (N56.0585 W03.6249) on the north shore of the Firth of Forth, which was part of his estate. These were erected in 1781. Dundonald was an inventive man but most of his industrial enterprises ended in failure, as did this one. The Navy did not coat with tar the bottoms of their ships with sufficient enthusiasm to prevent Dundonald from going bankrupt.

Other Places

All round Scotland there are other sites, some very small and isolated, which have strong associations with scientific personalities, who inevitably had to travel to large conurbations to conduct their work. Here are five 19th-century examples.

Hugh Miller (1802-1856) was a stonemason who went on to write a number of widely read books on geology. He was born in Church Street, Cromarty (N57.6801 W04.0308), to the north of Inverness. His books include *The Old Red Sandstone* of 1841, *Footprints of the Creator* (1850) and *Testimony of the Rocks* (1856). His birthplace is open to the public and run by the National Trust for Scotland (Figure 11).

Alexander Bain (1810-1877) was born in the tiny village of Watten (N58.4723 W03.2995) at the very north of the Scottish mainland. He was apprenticed to a watchmaker in nearby Wick and went on to the invent the electric clock (an example is in the National Museum of Scotland, Chambers Street, Edinburgh). Bain did most of his inventing in London and Edinburgh (where a plaque on 21 Hanover Street records his workshop there between 1844 and 1847). He died in Kirkintilloch in the west of Scotland and his headstone can be found in the Old Aisle Cemetery. There is a granite monument to Bain in his village and a plaque on the Council Offices at Wick in the Market Place (N58.4389 W03.0937) – next to the Alexander Bain public house.

John Muir (1838-1914), the nature conservationist, was born in the seaside town of Dunbar in East Lothian. It lies 29 miles east of Edinburgh and is easily reached by train from Edinburgh. Muir's family emigrated to the United States in 1849, establishing a farm at Portage, Wisconsin. Muir is mainly remembered as the person who pressed Congress for the preservation of wilderness areas, two of which became Yosemite and Sequoia National Parks. His birthplace at 128 High Street, Dunbar, is now a museum telling the story of his life. From April to September it is open seven days a week; during other months of the year it is closed on Mondays and Tuesdays. Check by calling +44 1368 865899. The cliffs and coastline at Dunbar are part of the John Muir Way, a walking route from Edinburgh to the Scottish Borders.

Down the coast from Dunbar, at Siccar Point in Berwickshire, lies James Hutton's famous Unconformity in the geological strata of the rocks. It was described by him in 1788 and it indicated the principle of Uniformitarianism, whereby geological features are laid down in a self-maintaining, infinite cycle rather than by catastrophic events. He famously wrote that the Earth offered "no vestige of a beginning, no prospect of an end."

John Logie Baird (1888-1946) was an inventor of the television. Leaving Scotland in attempt to improve his health, he was able to show, in the period between 1923 (in Hastings) and 1925 (in London), that his system worked. He demonstrated the world's first color transmission in 1928. Baird was born in Helensburgh (N56.0023 W04.7340), on the River Clyde and to the west of Glasgow, in 1888. His achievement is recorded on a plaque on the south-west corner of the town's Municipal Building (Figure 12).

Figure 11. Hugh Miller's cottage, Cromarty, where he was born in 1802.

Figure 12. Plaque commemorating John Logie Baird on the Helensburgh Municipal Buildings.

Conclusion

It is fair to say that Scots have excelled through the whole gamut of science, technology and medicine. Only a small sample could be included in this chapter and there is much more to be discovered by the visitor to Scotland. There has been no space to include, for example, Joseph Black's original concept of latent heat of 1762, of the work of refugee scientist and Nobel Laureate, Max Born (1882-1970), Tait Professor of Natural Philosophy at Edinburgh from 1936 to 1952, or of the work which took place at the Roslin Institute that resulted, in 1996, in the first mammal ever being cloned, Dolly the Sheep (named after Dolly Parton). All this, and much more, would deserve a book of its own.

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Chapter 4

London as a Center of Science

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London's centrality in science can be attributed to a number of factors, not least of which is that she is the seat of government, site of the headquarters of many learned societies, center of a seafaring empire for several centuries, a flourishing commercial center, and the nexus or near-nexus of the major institutions of higher education in the country. This chapter is an introduction to every scientific facet of this fascinating city in the form of a gargantuan walking tour.

Introduction

London is clearly a major center of scientific activity and has been for at least 3 centuries, but why? It is its role as capital city and seat of government that is crucial, making London the natural location for learned societies, national museums and national research organizations such as the National Physical Laboratory or the Laboratory of the Government Chemist. As home to the powerful: the royal family, political leaders, and the top civil servants of government, London inevitably attracted the wealthy and hence it has always been a major market for luxury goods. Furthermore, as the center of a seafaring empire until the mid-20th century and a major port in its own right, London was the natural location for the state observatory with the aim of finding a way to determine longitude at sea. The demand for instruments for state use (for example hydrometers to measure alcohol content), instruments as luxury items (such as opera glasses) and instruments for use at sea (sextants, compasses and telescopes) meant that London was an important center of scientific-instrument-making until the 1970s. James Watt (1736-1819) learned his trade as an instrument-maker in London, and there were many important firms ranging from the Dollonds and John Browning to more recently Adam Hilger and Bellingham and Stanley.

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For many years Holborn in general and Kingsway in particular was a center for scientific instrument dealers. Broadhurst, Clarkson & Co. (the successors of the early instrument-maker Benjamin Martin) had a well-known shop at 63 Farringdon Road between 1908 and 2006. Also catering to a wealthy clientele, pharmaceuticals and fine chemicals were also major industries in London up to the end of the 20th century with firms such as Allen and Hanbury, May and Baker, and Howards. It has to be said that the history of science in London, apart from Humphry Davy (1778-1829) and Michael Faraday (1791-1867) at the Royal Institution, is not dominated by individuals. Surprisingly, with a few marginal exceptions, there were no institutions of higher education in London until the foundation of the non-denominational University College in 1826, followed by the Church of England sponsored King's College in 1829. This was a result of the long-standing monopoly of university education in England by Oxford and Cambridge. Among the exceptions were Gresham College (see below), which provided free lectures for anyone who wished to attend, and the dissenting academy New College at Hackney (flourishing for ten years between 1786 and 1796 and where Joseph Priestley taught) that provided education for those who could not satisfy the religious requirements of Oxford or Cambridge. The Royal College of Chemistry was set up in 1845 and since then, London has had a number of colleges associated with the University of London (a confederation of colleges) and other institutions of higher education. London is very large in area and while science in London is to some extent concentrated in the Piccadilly area and South Kensington, some of the sites of interest are far apart. For this reason I have not covered sites on the outskirts of London unless they are of considerable interest. Nor for lack of space have I included sites of relatively little interest (plaques, statues, places where scientists lived) that one might have covered in a less well-endowed city (*1*). When travelling round London, it is best to use the tube (subway) or walk. Buses are numerous and frequent, but their progress is hindered by the congestion on the roads and it can be complicated to work out which bus to take. Buses do not take cash fares and visitors should obtain an "Oyster card" to travel on public transportation. To work out your route beforehand use the journey planner on the TFL (Transport for London) website. Taxis are convenient for short trips, but are expensive (roughly $10 a mile plus a 10% tip). I would advise strongly against using an automobile in London. The traffic in London is often heavy and drivers have to pay a "congestion charge" in central London. There are bicycles one can hire using a credit card for short trips (known locally as "Boris bikes"), but cycling in London is very dangerous and there have been many fatal accidents.

Around Piccadilly Circus—The Learned Societies

The area between Piccadilly and the Mall houses many of Britain's learned societies, above all Burlington House, which is the starting point for our tour. It is located halfway along Piccadilly between Green Park tube station (Piccadilly and Jubilee Lines) and Piccadilly Circus tube station (Piccadilly, Bakerloo and Northern Lines). It is also a five-minute walk from the Royal Institution (*2*).

Just walk down Albemarle Street, turn left into Piccadilly and along the road to Burlington House, which is opposite the famous high-class grocers, Fortnum and Mason. Sir John Denham built Burlington House (Figure 1) in 1664 when Piccadilly was still in the country, but he sold it before it was completed to Richard Boyle, 1st Earl of Burlington, the son of the Anglo-Irish adventurer Richard Boyle, 1st Earl of Cork and the brother of the alchemist Robert Boyle (1627-1691). Richard Boyle completed the house, but his great-grandson Richard Boyle, 3rd Earl of Burlington, who succeeded to the title as a boy in 1704, was keen on the new Palladian architecture so he rebuilt the house with the help of the pioneering Palladian architect Colen Campbell and the interior designer William Kent. After his death, Burlington House (N51.5088 W0.1392) passed to the Dukes of Devonshire, who had little interest in it.

Figure 1. Burlington House: The Royal Society of Chemistry. Photograph: Creative Commons.

After belonging to Lord George Cavendish, a direct descendent of the Earls of Burlington (and was himself made the 1st Earl of the new creation) and a distant relative of the natural philosopher Henry Cavendish (1731-1810), the house was bought by the British government as the site for London University. This plan was abandoned because of the public opposition to the demolition of Burlington House and the main (north) wing of the house was taken over by the Royal Academy in 1867. Meanwhile the Royal Society, the Chemical Society and Linnean Society had already moved into the east and west wings, which were rebuilt in 1873, when the Geological Society, the Royal Astronomical Society and the Society of Antiquities also moved to Burlington House. The Chemical Society shared the east wing with the Royal Society, which moved to Carlton House Terrace in 1967. The British Academy (which represents the humanities) occupied the premises vacated by the Royal Society until 1983 when it moved to Cornwall Terrace in Regent's Park. It is now located in Carlton House Terrace, on the other side of the Duke of York Steps from the Royal Society.

The Chemical Society of London was founded by Robert Warington (1807-1867) at the Society of Arts in 1841, the same year that the (Royal) Pharmaceutical Society was formed. Warington had been a chemist at the Truman, Hanbury, & Buxton brewery and in 1842 he became chemical operator at Apothecaries' Hall. He was also one of the founders of the Royal College of Chemistry at 299 Oxford Street (a Moss Bros. clothes shop currently occupies this site). A plaque to the original site of the RCC can be seen on the side of the entrance to no. 299 Oxford Street. The Chemical Society received its Royal Charter in 1847. It was always a learned society open to anyone with an interest in chemistry (in the same way as the Royal Astronomical Society is today), but a professional body for chemists, the (Royal) Institute of Chemistry was established in 1877. The Chemical Society was located at Burlington House from 1857 and the Royal Institute of Chemistry had its purpose-built headquarters (including laboratories) at 30 Russell Square, next to the later Senate House of the University of London, from 1914. The building is now used by Birkbeck College of the University of London, but there is still a bust of Joseph Priestley over the entrance on the south side. The two organizations merged in 1980 along with the Society for Analytical Chemistry (founded in 1874) representing professional analysts and the Faraday Society (founded in 1903) supporting physical chemistry. The Society of Chemical Industry founded in 1881 by John Hargreaves and Ludwig Mond finally decided not to take part in the merger and retains its large premises at 14/15 Belgrave Square near Hyde Park Corner. The Chemical Society expanded its premises in the east wing of Burlington House when the Royal Society left in 1967 and again when the British Academy departed in 1983. However many of the back office operations, for example publications, are now carried out in Thomas Graham House in Cambridge Science Park, opened in 1989.

The Royal Astronomical Society was founded as the Astronomical Society of London in 1820 and William Herschel (1738-1822) was the largely honorary first president, his son John Herschel (1792-1871) being one of the moving forces behind its formation. Initially after a brief nomadic period, the society rented rooms in Lincoln's Inn Fields until 1834, when the British government gave the Royal Astronomical Society (as it had become in 1831) rooms in Somerset House in the Strand. Forty years later the society moved to the west wing of Burlington House where it remains to this day. Unusually for a modern learned society, the Royal Astronomical Society still has a mixture of professional and amateur members although the British Astronomical Association (founded with the RAS's help in 1890) caters specifically for the needs of amateurs and has rooms in the RAS's premises at Burlington House.

Like the Royal Astronomical Society thirteen years later, the Geological Society of London was founded as a result of a dinner at the Freemasons' Tavern in 1807. The Freemasons' Tavern stood in Great Queen Street off Kingsway in Holborn, close to the large Freemasons' Hall, the headquarters of English freemasonry, further down the same street and the Grand Connaught Rooms now stand on the site. The English Football Association was founded in the same tavern in 1863. Chemists were prominent among its founding ranks, including Humphry Davy, William Haseldine Pepys (1775-1856) and Richard Phillips (1778-1851) who was also one of the founders of the Chemical Society. A royal charter was granted in 1825 and three years later the society moved from 20 Bedford Street to Somerset House. Earlier it had shared premises in Lincoln Inn Fields with the Medical and Chirurgical Society, who later hosted the Royal Astronomical Society. In 1874 it moved to Burlington House, mostly in the east wing.

The Linnean Society of London was founded in 1788 by Sir James Smith—who had acquired Carl Linnaeus' plant and animal collections (and his personal library) five years earlier—for the promotion of natural history. These collections (and Smith's own collection) are still preserved by the society. It was at a meeting at the Linnean Society that Charles Darwin (1809-1882) and Alfred Russel Wallace (1823-1913) gave their papers on natural selection and evolution in 1858. The society's library is open to the public, but you should contact the library to arrange your visit beforehand (*3*).

You should now walk along Piccadilly towards Piccadilly Circus. The statue of "Eros" in the middle of Piccadilly Circus is one of the iconic sights of London, but may seem to have little to do with science. However it is the earliest cast aluminum statue in England and a rare example of aluminum made using the chemical process developed by the French chemist Henri Sainte-Claire Deville (1818-1881) rather than the later electrochemical process. Designed by Alfred Gilbert, it was erected as a memorial for the philanthropist and reformer Anthony Ashley Cooper, 7th Earl of Shaftesbury, and is intended to represent the "spirit of charity" rather than the Roman god of love. Turn right at Eros and down the major shopping thoroughfare of Regent's Street and continue down Waterloo Place which is effectively the same street. As we walk down Waterloo Place we pass the impressive home of the Athenaeum Club founded in 1824, with its gilded statue of Athena and the classical frieze copied from the Parthenon in Athens. While it is a gentleman's club whose members are mostly well-off, like the other gentlemen's clubs in nearby Pall Mall, it has always made a point of electing members of intellectual distinction who may not be particularly wealthy. Hence it has had a large number of scientists amongst its members, most notably Michael Faraday, and traditionally Keepers at the Science Museum were usually members, although women were only admitted as full members in 2002. As a result it is famous for the quality of its library and it was one of the first buildings in London to be fitted with gas lighting (in 1832) and electric lighting (in 1886).

We now come to Carlton House Terrace, the site of Carlton House built by Henry Boyle, 1st Baron Carleton. Carleton is the correct spelling of his title (it is a village near Pontefract in West Yorkshire), but everything named after him is spelled Carlton. Boyle was the great-grandson of the 1st Earl of Cork and at his death the house passed to the 3rd Earl of Burlington, who rebuilt Burlington House, but Carlton House then came into the possession of the Royal Family. The building was demolished in the late 1820s and replaced by large houses designed by John Nash. Nos. 6 to 9 are now occupied by the Royal Society (N51.5059

W0.1325). The Royal Society arose from a group of men interested in scientific experiments who first came together at Wadham College in the 1640s. After the Restoration in 1660, its center was Gresham College and the society was formed in November 1660 after a lecture by Christopher Wren (1632-1723), who was the professor of astronomy there. They planned to meet weekly to witness experiments and appointed a curator of experiments, Robert Hooke (1635-1703). King Charles II was told about the society's work and gave his royal approval, with a second royal charter in 1663. Up to the 19th century the membership of the society was similar to that of other learned societies in London (in contrast to the continental academies of science) in that fellows had to be elected but they need not be active natural philosophers. The notion that it was beneficial for scientists and wealthy amateurs to mingle together was finally rejected by a group of reformers in 1847 and replaced by an elite group of leading scientists, elected by merit, at least in theory. The British government then began to channel its financial support for science through the Royal Society, beginning with £1,000 in 1850, the society thus acting for many years as a kind of research funding council (*4*). The Royal Society moved from Gresham College to Crane Court off Fleet Street in 1710, near Dr. Johnson's House and close to the former offices of William Crookes' (1832-1919) *Chemical News* in Red Lion Court a century and a half later. In 1780, the Royal Society moved to Somerset House under the redoubtable leadership of Sir Joseph Banks (1743-1820), who was President between 1778 and 1820.

Gresham College was founded in 1597 in the mansion of Sir Thomas Gresham in Bishopsgate in the City of London, where the Tower 42 building now stands. After 1768 the college had no permanent home until it was settled at New Gresham College in Gresham Street off Moorgate in 1842. Finally in 1991 it moved to Barnard's Inn Hall (N51.5179 W0.1102) near Holborn. Free public lecture courses are still given there by the Gresham professors, eminent lecturers who have permanent positions elsewhere and who are appointed on a rotating basis, usually every four years. Barnard's Inn was the home for many years of the eccentric Irish chemist and alchemist Peter Woulfe (1727-1803) in the late 18th century. He invented the double necked (or triple necked) flask for washing gases, properly called the Woulfe bottle, but often misspelled Woulff (a backformation from the German woulffsche) or even Wolff.

Please note that for the following sections, tables are provided with pertinent information for visits to the museums and other venues described.

Near Trafalgar Square

Go down the Duke of York steps—the column at the top (N51.5063 W0.1318) is a memorial to Frederick, Duke of York (1763-1827), Commander-in-Chief of the British Army and the "Grand Old Duke of York" of the nursery rhyme—to the Mall and turn left and walk to Trafalgar Square. You can either walk diagonally across Trafalgar Square towards the Church of St-Martin-in-the-Fields with its spire and then up St. Martin's Place to the memorial to Edith Cavell and the National Portrait Gallery or you can walk along the south side of Trafalgar Square to the Strand, where we will pick up the tour again shortly. The National Portrait

Gallery (*5*) was founded in 1856 and moved to its present site near Trafalgar Square next to the National Gallery forty years later. Its aim is to portray people who have been significant in British history and culture, and the artist or photographer is unimportant in that context. Scientists, not surprisingly, feature in its collections, but they are not prominent. In fact only four scientists are currently on display, namely Charles Darwin (by John Collier), Sir Isaac Newton (1643-1727), Sir Christopher Wren (by Kellner) and Michael Faraday (by Thomas Phillips).

Going down the east side of Trafalgar Square we reach the Strand. We then walk down the Strand to the second street on the right, Craven Street. The College of Optometrists is located at 42 Craven Street (N51.5078 W0.1252), which is near the Charing Cross and Embankment underground stations and Trafalgar Square. It is also about 15 minutes' walk from Piccadilly Circus. The museum of the British Optical Association was founded in 1901 and was taken over by the College of Optometrists when the British Optical Association was disbanded in 1980. It contains some twenty thousand objects and archival items relating to the history of ophthalmic optics (optometry), the human eye and visual aids, and the representation of these subjects in art. It is open to the public but prior notice is required by writing to the museum (*6*). In the same street as the BOA museum, at number 36, is Benjamin Franklin House where the American scientist and statesman lived between 1757 and 1775. The house is a combination of a dramatic presentation of Franklin's stay in London and a small science center for students. There is also a scholarship center, which contains a set of Franklin's published papers (*7*).

Westminster Abbey

Continue down Craven Street and Northumberland Avenue (which Craven Street merges into) to the Embankment. Turn right along the Embankment—viewing the "London Eye" on the south bank and the Royal Festival Hall, the only remaining part of the Festival of Britain there in 1951—and we arrive at the Houses of Parliament. Turning right and then left alongside Parliament Square we reach Westminster Abbey, a twenty-minute walk from Craven Street. This medieval church, formerly a Benedictine abbey, is well known and will not be described here. However it contains the tombs or memorials of several famous scientists that are germane to this chapter. Above all, the abbey is the final resting place of Sir Isaac Newton, whose elaborate monument (Figure 2), near his grave, was commissioned from the sculptor Michael Rysbrack and the architect William Kent by his nephew-in-law John Conduitt. Completed in 1731, it has all the symbols of Newton's experimental work (prism and telescope) and his work as Master of the Mint (the furnace may refer to his alchemical work, but this is unlikely as it was not well known at the time). His right elbow rests on several books representing his great works, namely "Divinity," "Chronology," "Opticks," and "Philo. Prin. Math" (the *Principia*). The pyramid in the background has a celestial globe and the path of the great comet of 1680 (not to be confused with Halley's comet of 1682), which Newton used to develop his laws of gravity. Note that the date of Newton's death is given as 20th March 1726, which is the old style year that ended on 24th March. In the modern calendar introduced 25 years later, Newton died in 1727 on 31 March.

Figure 2. Newton's Monument in Westminster Abbey. Below: Detail of his Accomplishments. Photograph: Wikimedia Commons.

The other famous scientist in the abbey is Charles Darwin who is buried near Newton. Anyone who is interested in the background of Britain's most famous agnostic being buried in such an important church is encouraged to read the paper by James Moore (*8*). Apart from Newton and Darwin, few scientists are actually buried here. The most famous is the physicist William Thomson, Lord Kelvin (1824-1907), who is buried in the same area. One of the moving forces behind Darwin's burial, and President of the Royal Society at the time, William Spottiswoode (a mathematician and a partner of the publishing firm Eyre and Spottiswoode) is buried in the south transept away from his fellow scientists. By contrast Sir John Herschel, the astronomer and pioneering photographic chemist, lies close to Newton and Darwin. Next to his grave there is a later memorial to his father William Herschel. The ashes of J. J. Thomson (1856-1940) of electron fame are also buried near Darwin and Newton. John Woodward (1665 or 1668-1728) who established the Woodwordian chair of fossils (now geology) at Cambridge in 1728 is buried in the nave. Finally we should note the resting place in St. Nicolas's chapel of Thomas Sprat (1635-1713), an early fellow of the Royal Society who wrote the first history of the society.

There are several memorials in the abbey to scientists who are not buried there. Many of them are near Newton's tomb, which is sometimes called scientists' corner (after the model of Poets' Corner). However there are (sadly) relatively few chemists. The most famous are Humphry Davy (in St. Andrew's chapel) and Michael Faraday (if we consider him to be a chemist as he would have regarded himself to be, rather than a physicist). Similarly there is a memorial to James Prescott Joule (1818-1889) who could be considered to be a brewing chemist rather than a physicist (and who probably pronounced his surname as Jowl not Jool). There is also a memorial to Sir William Ramsay (1852-1916) and his fellow discoverer of argon, John William Strutt (1842-1919), 3rd Baron Rayleigh (St. Andrew's chapel). The physician John Freind (1675-1728), who was briefly professor of chemistry at Oxford University at the beginning of the 18th century, is memorialized in the south aisle. The natural philosophers and physicists remembered in the abbey include John Couch Adams (1819-1892; who worked out the position of Neptune independently of Urbain Le Verrier), Paul Dirac (1902-1984), Robert Hooke (lantern area), Jeremiah Horrocks (1618-1641; west door nave), James Clerk Maxwell (1831-1879), and George Gabriel Stokes (1819-1903). Edmond Halley (1656-1742) has a modern memorial with a comet motif in the south cloister. Howard Florey (1898-1968) of penicillin fame has a memorial near Darwin's tomb. The pioneering Oxford geologist William Buckland (1784-1856) has a memorial bust in the nave. Lastly there is a small bronze-coated bust of James Watt, who considered himself to be a chemist not an engineer, in St Paul's chapel, which replaced the massive marble statue by Sir Francis Chantry in 1960 and now in the Scottish National Portrait Gallery in Edinburgh (qv).

Table 1. London Venues: Trafalgar Square and Westminster

Venue	*Address*	*Opening Hours*	*Website/Other Information*
National Portrait Gallery	St. Martins Place	Daily 10:00 AM to 6:00 PM (Th, F until 9:00 PM)	(*9*); FREE
British Optical Association Museum	42 Craven St.	M–F 9:30 AM to 5:00 PM by appointment only	(*10*): FREE
Benjamin Franklin House	36 Craven St.	W−M 10:30 AM to 5:00 PM	(*11*); ADULTS £7
Westminster Abbey	Abingdon St.	Variable – see Calendar	(*12*); ADULTS £18

Close to Lambeth Palace

Leave Westminster Abbey and return to Millbank on the riverbank, walk along the north side of the road to 9 Millbank (N51.4955 W0.1253) which is now the offices of Ofgem (the state regulator of the electricity and gas markets in the UK), but it was Imperial Chemical House—the headquarters of ICI, the giant chemical firm—until the early 1990s. The neo-classical building was designed by the government architect Sir Frank Baines and completed in 1931. It is most famous for its nickel-copper alloy doors with sculptured relief images of agriculture, industry and science both ancient and modern, including the Mount Wilson observatory; they are, fortunately, still in place. Across the nearby roundabout you can see the parallel building Thames House, now the headquarters of the Security Service (MI5), the British counter-intelligence agency. Cross Lambeth Bridge to the Garden Museum (formerly the Museum of Garden History) located next to Lambeth Palace. It is housed in the former church of St. Mary-at-Lambeth, the resting place of the pioneering plant collector, John Tradescant the Elder (1570-1638). The Tradescants (father and son) are not only important for the development of modern gardens, but their collections, acquired by Elias Ashmole (1617-1692) were also the driving force behind the establishment of the (Old) Ashmolean Museum (now the Museum of the History of Science) in Oxford (qv.). The museum is a combination of permanent and temporary displays. The connections between chemistry and gardening are not emphasized perhaps out of fear of annoying organic gardeners, but the knot garden (a formal garden design using hedges to create the form of a knot), that contains Tradescant's tomb is remarkable. It is worth emailing the museum beforehand to check the current opening hours and temporary exhibitions. If you wish to join the other tour (to the Hunterian Museum, see below) get the 77 bus to Waterloo Station and then the 521 bus to Holborn Station, the journey is about 40 minutes.

Crossing Covent Garden

Alternatively from Craven Street walk back to the Strand, cross the road and turn right. Walk along until you see the blue and white clock of the Civil Service Supply Association high up on the wall on a corner. Turn left to go up Bedford Street and then turn right into Maiden Lane. Halfway down Maiden Lane on the left is Rules, founded in 1798. It is the oldest restaurant in London and was popular with King Edward VII. Near the end of Maiden Lane on the right hand side of the road is Corpus Christi, a Roman Catholic church which is the site of the "Golden Phoenix," the phosphorus-making and pharmaceutical laboratory established by Robert Boyle's laboratory assistant Ambrose Godfrey (formerly Gottfried) Hanckwitz (1660-1741) in 1707. At the end of Maiden Lane, turn left into Southampton Street, then right into Henrietta Street. You will now arrive at Covent Garden, formerly London's vegetable, fruit and flower market which was moved to New Covent Garden, located three miles southwards at Nine Elms on the south bank of the Thames, which is also the site of the new US Embassy (due to open in 2017). Here you will find the London Transport Museum, which is about the history of transport in London in the last 200 hundred years, but is particularly strong on the London Underground, the world's oldest subway system. Its forerunner, the Museum of British Transport, opened in a former bus garage in Clapham in the 1960s, then moved to Syon Park in west London in 1973 and seven years later, it was reopened in the Victorian Flower Market building in Covent Garden as the London Transport Museum.

Leaving Covent Garden on the eastern side at Russell Street, we walk along this street (which becomes Kemble Street after it crosses Drury Lane) until we come to Kingsway in Holborn. Crossing Kingsway, we leave it again at Sardinia Street which leads to Lincoln's Inn Fields. Walk along to the south side of this square to the Royal College of Surgeons on the far corner. It is about twenty-five-minutes' walk from Craven Street and twelve minutes from the London Transport Museum. Holborn underground station is ten minutes' walk away and Temple underground station is 15 minutes. The Hunterian Museum at the Royal College of Surgeons was formed when the medical collections of the Scottish surgeon and anatomist John Hunter (1728-1793) was bought by the British government and given to the then Company of Surgeons. Since then they have been supplemented by other collections including the John Evelyn's (1620-1706) anatomical tables (*13*) in 1809, which were previously at the Royal Society and then the British Museum. The objects are connected with anatomy, pathology, surgery, dentistry and medical teaching. The displays were completely renovated in 2005 and there are also temporary exhibitions. The museum should not be confused with the Hunterian Museum at the University of Glasgow. There is a curator's tour every Wednesday at 1.00 PM. Sir John Soane's famous architectural museum is across the square from the college and the London School of Economics lies between the Royal College of Surgeons and the Strand.

From the Royal College of Surgeons, you can walk to the south-east corner of Lincoln's Inn Fields, turn right into Serle Street, left into Carey Street, the former location of the bankruptcy court (hence "in Carey Street" is a phrase for being bankrupt). Then turn right down Bell Yard and left into Fleet Street, the former home of many British newspapers until the 1980s; then turn right briefly along Farringdon Street before crossing the road and turning left into Pilgrim Street. Waithman Street is first on the right and it leads to Apothecaries' Hall, the headquarters of the Worshipful Society of Apothecaries. After the hall was rebuilt following the Great Fire of London in 1666, the Society established a pharmaceutical manufacturing "Elaboratory" at the Hall in 1671, and this became a major manufacturer of pharmaceuticals by the end of the 18th century. It is possible to visit the hall by prior arrangement although it is not generally open to the public. Contact details can be found on the Society's website (*14*). However one can see the exterior from the street, including the great cistern in the courtyard. It is 20 minutes' walk from the Royal College of Surgeons and 40 minutes along the Thames Embankment from Westminster Abbey. Apothecaries' Hall is near Blackfriars railway and underground station and St. Paul's underground station (and St. Paul's Cathedral); it is a short tube ride between Westminster and Blackfriars (on the District and Circle Lines).

After visiting Apothecaries' Hall, you may wish to take a 20-minute walk along Carter Lane and Cannon Street to the Monument to the Great Fire of London (Figure 3), which is a Doric pillar which stands close to the pie shop where the Great Fire started in the early morning of 2 September 1666; in fact, it is as far from that spot as it is tall (202 feet, 62 meters). It is actually on the site of St. Margaret's church, which was the first of 87 churches to be destroyed by the Great Fire. The tower was designed as a scientific laboratory by Wren and Hooke, for several purposes: to be used as a zenith telescope; for barometric pressure determinations (each of the 311 steps is exactly six inches high for this purpose); and as an underground laboratory for pendulum experiments. It is possible to walk up the Monument to view the City of London (although decreasingly so as the number of skyscrapers in the area continues to grow). Originally the distinctive urn of flames at the top was going to be a statue of King Charles II but this would have interfered with the zenith telescope (*15*).

The Monument underground station is next to the tower. Bank underground station and Fenchurch Street railway station are nearby. If you wish you can make a 25 minute train journey from Fenchurch Street to Upminster where you can see St. Laurence Church in the middle of the town, from the tower of which (the present day steeple is Victorian) the Reverend William Derham FRS measured the speed of sound in air accurately for the first time in 1705. He accomplished this by observing the flash of a gun on Blackheath across the River Thames and measured how long the sound took after the flash by using a pendulum. He is buried in the church but the location of his resting place is unknown. He also used his telescope for astronomy and drew up a list of 11 nebulae (most of which he took from Johannes Hevelius, the 17th century German-Polish astronomer, and several do not in fact exist), including the Andromeda Nebula. Or you can walk across London Bridge just south of the Monument and take a train to the Horniman Museum (see below).

However, you can also walk up Fish Street Hill to Eastcheap which joins Tower Hill (a street rather than a geological feature), cross the street and walk along the right side of the street (i.e. the south side)—with the famous Tower of London on your right—then turn right at Tower of London Park (a grassy corner) into East Smithfield. The headquarters of the Royal Pharmaceutical Society (from April 2015) is at 66-68 East Smithfield, a modern building is on the left-hand side of the road. The walk from the Monument is 25 minutes and you can walk from Tower Hill tube station in ten minutes. The Pharmaceutical Society was founded in 1841 by three Quaker pharmacists, John and Jacob Bell and William Allen at the Crown and Anchor tavern in the Strand which was famous in its day but no longer exists. On one hand chemists and druggists were struggling to be free of the monopoly of the apothecaries and physicians (an aim partly achieved in 1815) and at the same time sought to regulate themselves to improve their reputation. At the same time chemists were striving to distinguish themselves from chemists and druggists, which was one of the motivations behind the formation of the Chemical Society in the same year. In Britain, the chemists failed miserably in this aim. A "chemist" to the ordinary member of British public is what most countries would call a pharmacist or apothecary, not a scientist, although this may be beginning to slowly change. The museum consists of a permanent exhibition about the evolution of the pharmacy and making medicines. It also has fine collections of English Delftware and foreign drugs jars, and bell metal mortars; both dating mainly from the seventeenth and eighteenth centuries. Contact the museum for further information (*16*).

Figure 3. The Monument. Photograph by mwanasimba, under license from Creative Commons.

Table 2. London Venues: Near Lambeth Palace and Covent Garden

Venue	*Address*	*Opening Hours*	*Website/Other Information*
Garden Museum	5 Lambeth Palace Rd.	Su–F 10.30 AM to 5:00 PM (Sa till 4:00 PM	(*17*); (occasional closings) ADULTS £7.50
London Transport Museum	Covent Garden Piazza	Daily 10:00 AM to 6:00 PM	(*18*); ADULTS £15
Hunterian Museum at the Royal College of Surgeons	35-43 Lincoln's Inn Fields	Tu–Sa 10:00 AM to 5:00 PM	(*19*); FREE
The Monument	Fish Street Hill	Daily 9:30 AM to 6:00 PM	(*20*); ADULTS £4
Royal Pharmaceutical Society Museum	66-68 East Smithfield	Temporarily closed for re-location	(*21*)

Roaming in Bloomsbury

Alternatively, from the Hunterian Museum you can walk along the western side of Lincoln's Inn Field up to Gate Street, then along Gate Street and Kingsway to Holborn station and then continue walking to the British Museum on Great Russell Street in the center of Bloomsbury, the famous haunt of interwar intellectuals. It is ringed by no less than four underground stations: Goodge Street (Northern Line) in the north-east, Russell Square (Piccadilly Line) in the north-west, Holborn (Piccadilly and Central Lines) in the south-east and Tottenham Court Road (Northern and Central Lines) in the south-west. I always go to Holborn station, cross Kingsway and turn right to head north until I reach the neo-classical archway of Sicilian Avenue (a pedestrianized precinct), go along the avenue to Bloomsbury Square gardens, cross the gardens to the north-western (top left) corner, turn left and then walk a short distance to the British Museum. It takes about ten minutes at most from Holborn station and fifteen minutes from the Royal College of Surgeons. The physician and President of the Royal Society Sir Hans Sloane (1660-1753) built up a major collection during his life in the early 18th century. When he died in 1753, his will offered the collection to the nation in return for a payment of £20,000 to his heirs. £20,000 ($30,000) in 1753 is worth £2.7 million ($4 million) in 2014, but in terms of average income, it would now be worth £45.3 million ($68 million). The British government accepted this offer and set up the British Museum to house Sloane's collection, which is made up of books and manuscripts, coins and medals, a herbarium (dried plants) and antiquities from both Britain and abroad. The book collection became the basis of the famous British Museum library, which became the British Library in 1973 and moved to Euston Road in 1997. The natural history collections were moved to South Kensington in 1883. The present British Museum (Figure 4) is thus based on the collection of coins, medals and antiquities, but of course it has been much expanded since Sloane's death (*22*). One of its most famous acquisitions was the Parthenon sculptures (popularly known as the Elgin marbles) from the 7th Earl of Elgin, in 1816 which are now in Room 18 (Greece: Parthenon). There was much concern about the state of the sculptures, partly because of damage caused before they left Greece, partly a result of the prevailing air pollution of London and partly because of a misunderstanding that ancient Greek sculptures were pure white (when in actual fact they were painted and also acquired a patina over time). Michael Faraday was consulted in 1830 and more extensively in 1838 when he recommended the use of washing soda solution to clean the stone rather than soap, partly because it was more easily rinsed off. Unfortunately a very strenuous scraping process was used to clean some of the sculptures before they were housed in the new Duveen gallery in 1938 and this unwittingly removed much of the fine detail from the stonework. Another famous antiquity in the museum is the Rosetta stone in Room 4 (Egyptian sculpture) which was discovered by the Napoleonic expedition to Egypt in 1799. After the capitulation of the French forces two years later, the stone fell into British hands and was given to the British Museum in 1802. The famous scientist and polymath Thomas Young (1773-1829) was one of the experts who worked on the inscriptions and translated the demotic Egyptian text in 1814, eight years before the French philologist Jean-François Champollion (1790-1832) deciphered the hieroglyphs.

In Room 61 of the museum (Egyptian Life and Death), you can see one of the most ancient pieces of Egyptian glass, a blue glass kohl jar produced during the reign of the pharaoh Thutmose III (reigned 1479-1425 BC) who had probably acquired glassmaking technology during his invasion of Syria. While the Egyptians could make glass from quartz sand and natron (soda), they lacked glass-blowing and thus could only use molten glass as a plastic material, for example molding it and twisting it. Glass-blowing also originated from Syria, but from around 50 BC. In Room 70 (Roman Empire) you can see one the earliest examples of glass-blowing, a glass box made by blowing glass into a mould, from Sidon in Phoenicia from 25-50 AD. Another early plastic material is natural lacquer, obtained from the poisonous sap of the lacquer tree (*Rhus verniciflua*). The lacquer is painted in thin coats onto the base material such as wood, often hundreds of times and hence can take up to a year. The finished lacquer coat is then carved and left alone, or inlaid with other materials or filled in with gold powder. The lacquer can be dyed with cinnabar (mercury(II) sulfide) to make it red or with carbon black for a black lacquer. The technique has been used in China since Neolithic times. In Room 33 (Asia), you can see a lacquered box inlaid with silver and painted with cloud scrolls from southern China, which dates from the Han dynasty (206 BC to 220 AD).

When you come out of the British Museum's main (south) entrance turn right on Great Russell Street and then turn right into Gower Street and walk up to University Street on the left, with the dome of the main campus of University College London visible ahead on the right. On this corner is the Rockefeller Building and it contains the Grant Museum of University College London (UCL), the only surviving university zoology museum in London. It is about 15 minutes' walk from the British Museum. The nearest tube stations are Euston Square (Circle, Hammersmith and City, and Metropolitan lines), Warren Street (Northern and Victoria lines) and Euston (Victoria and Northern lines). It has a particularly notable collection of the bones of extinct species including the dodo, the quagga and the thylacine (Tasmanian tiger). There is also a beautiful collection of accurate glass models of marine creatures made by Leopold Blaschka and his son Rudolph in the late 19th century. The geology collection of UCL can be viewed in the Rock Room in the main UCL building (1st floor of the south wing) between 1 and 3 PM on Fridays. The museum was founded in 1854 and was a typical departmental museum in a period when many university departments worldwide had museums including many chemistry departments. The collections contain over 100,000 rocks, minerals and fossils. For further information, contact the museum (*23*). While you are in the main UCL building be sure to visit the philosopher Jeremy Bentham in his cubicle on the ground floor of the South Cloisters. It is mostly his skeleton covered by his clothes and padding, but the head is a wax model (his actual head is now considered to be too delicate to be part of the so-called auto-icon). There is also a small exhibition about the history of UCL (including its contributions to science) open to the public under the main cupola. On the far side of the main campus is the chemistry building on Gordon Street just before Gordon Square, with its somewhat brutalist modern façade. On the left of the entrance there is a RSC Historical Landmark plaque to the work of Christopher Kelk Ingold (1893-1970), the pioneer of organic reaction mechanism. The entrance hall, which is open to the public, has a small frequently changing display about the history of chemistry at UCL which is open to the public.

Figure 4. The British Museum Main Entrance. Photograph by Mary Virginia Orna.

From Gower Street go north and turn right onto Euston Road or from Gordon Street go north and turn left onto Euston Road to reach the Wellcome Collection, which is located in the headquarters of the Wellcome Trust in Euston Road almost opposite Euston Station. The nearest underground stations are Euston Square (Metropolitan, Hammersmith & City and Circle Lines) and Euston Station (Northern and Victoria Lines, and National Rail). The history of the Wellcome Collections begins with Sir Henry Wellcome (1853-1936), the American-born founder of the pharmaceutical company Burroughs Wellcome. During his lifetime, he established a medical collection and both this collection and the company were bequeathed to the Wellcome Trust on his death in 1936 (*24*). The medical collections were lent to the Science Museum in the 1970s where they are now on display on galleries on the 4th and 5th floors. However in 2007, after a new building had been erected for the Wellcome Trust next to the original (1932) building which had been refurbished, the Wellcome Trust opened new galleries to the public. The main galleries are about Wellcome and his collection: ("Medicine Man") and modern medicine ("Medicine Now") are open Tuesday to Sunday, 10 AM to 6 PM, and the café is open every day. There is usually a year-long thematic exhibition and more specific temporary exhibitions. Visit the website for the details of these exhibitions.

From the Wellcome Collection, cross the road and get one of the many buses going towards King's Cross station or turn right and walk for ten minutes to reach the British Library. The nearest railway and underground station is Kings Cross/St. Pancras. The British Library was formerly in the rotunda in the middle of the British Museum, which is famously where Karl Marx did his research for *Das Kapital*. Having been made a separate organization in 1973, the British Library moved to its current site in Euston Road in 1997. It is housed in a post-modernist building which was intended to blend in with the Gothic splendor of neighboring St. Pancras station but was (in)famously described by HRH Prince Charles as an "academy for secret police." In the courtyard there is a striking bronze sculpture by Eduardo Paolozzi representing Newton in the manner of William Blake. Originally the National Science Library was located at Patent Office Library in Chancery Lane, Holborn—although the Science Museum Library had claimed to be the national library of science from the 1920s to the 1950s—but it was amalgamated with the main library when it moved to the new building. You will need a reader's pass to use the collections (see the website for details), but there is a permanent exhibition of treasures of the library (including scientific works such as Galileo's *Sidereus Nuncius*) and temporary exhibitions which can be scientific in nature and are open to the public (*25*).

Rambling in Fitzrovia

Alternatively, turn left out of the Wellcome building, and left again into Tottenham Court Road. Go down the road and cross to turn right into Howland Street (which becomes New Cavendish Street when it crosses Cleveland Street) and finally left into Portland Place. The Association of Anaesthetists of Great Britain and Ireland has its headquarters at 21 Portland Place (N51.5195 W0.1450) almost opposite the BBC's Broadcasting House. It is about 25 minutes' walk from the Wellcome, but not easy to reach by tube being about ten minutes' walk from Oxford Circus station, Regent's Park station or Great Portland Street station. However there are buses up and down Portland Place and along Euston Road. There is an obvious overlap between anesthesia and chemistry from the early days of chloroform and ether in the mid-19th century. The association's Anaesthesia Museum is part of the Anaesthesia Heritage Centre, which also includes a library with a rare book collection and the association's archives. The museum, which contains objects relating to the history of anesthesia, has a permanent and a temporary display. The earliest object in its collections is a resuscitation set of 1774. Visitors should contact the museum beforehand (*26*). In the next block, at 64 Wimpole Street, there is the museum of the British Dental Association. It is advisable (but not necessary) to email the museum beforehand (*27*). Just turn left out of 21 Portland Place, walk down New Cavendish Street and then left again into Wimpole Street, it will take about 5 minutes.

If you turn right out of 21 Portland Place and take the first turn right into Duchess Street, then turn left down the famous medical thoroughfare Harley Street, you reach Wigmore Street. Turning left along Wigmore Street you soon reach the pharmacy of John Bell and Croyden on the corner of Welbeck Street, about ten minutes' walk all told. In a period when most British pharmacies simply sell household sundries (like an American drug store) and dispense packets of tablets prescribed by local physicians (called GPs, short for general practitioners), Bell & Croyden still retains the air (if not the appearance) of the traditional pharmacy. It is one of the last places in London that I know of where it is still possible to buy laboratory chemicals. John Bell (1774–1849) opened his pharmacy in nearby Oxford Street in 1796. John and his son Jacob became a campaigner for the right of chemists and druggists to dispense medicine in the face of the monopoly of the apothecaries. Jacob Bell (1810-1859) helped to found the Pharmaceutical Society in 1841 and set up the *Pharmaceutical Journal*. The pharmacy merged with Croyden & Co. in 1908 and moved to Wigmore Street in 1912. While it has retained its name, the pharmacy is now part of Lloyds, a national pharmacy chain.

Table 3. London Venues: Bloomsbury and Fitzrovia

Venue	*Address*	*Opening Hours*	*Contact or Website/Other Information*
British Museum	Great Russell St.	Daily 10:00 AM to 5:30 PM (F until 8:30 PM)	(*28*); FREE
Grant Museum of University College London	21 University Street	M–Sa 1:00 PM to 5:00 PM	(*29*); FREE

Continued on next page.

Table 3. (Continued). London Venues: Bloomsbury and Fitzrovia

Venue	*Address*	*Opening Hours*	*Contact or Website/Other Information*
Rock Room, Geology Collection, UCL	Room 4, 1st fl. corridor, South Wing, Gower St.	F 1:00 PM to 3:00 PM	(*30*); FREE
History of Chemistry Display	UCL Chemistry Dept., 20 Gordon St.	N/A	(*31*); FREE
Wellcome Collection	Wellcome Trust, 183 Euston Road	Tu–Su 10:00 AM to 6:00 PM (Th until 8:00 PM)	(*32*); FREE
British Library	96 Euston Road	M–Th 9:30 AM to 8:00 PM (F until 6:00 PM, Sa until 5:00 PM); Su 11:00 AM to 5:00 PM	(*33*); INDIVIDUAL TOUR £8
Anaesthesia Museum	21 Portland Place	M, Tu, Th, F 10:00 AM to 4:00 PM	(*34*); FREE (appointment recommended)
British Dental Association Museum	64 Wimpole Street	Tu, Th 1:00 PM to 4:00 PM	(*35*); FREE

The Albertopolis Tour

The Great Exhibition of the Works of Industry of all Nations was held in 1851 in the famous "Crystal Palace" in Hyde Park at the top of Exhibition Road, to the right of the entrance to the park. It was one of the few World Fairs to make a profit and the money was used by the Royal Commission for the Exhibition of 1851 to acquire land south of Hyde Park, which had previously been market gardens, to provide a home for a number of institutions including the South Kensington Museum (now the Science Museum and the Victoria & Albert Museum), the Royal College of Art, the Royal College of Music, the Royal Albert Hall and the Normal School of Science (now Imperial College). In 1862, there was the International Exhibition which was held in the grounds of the Royal Horticultural Society, which had been given to the society by the 1851 Commission. The Science Museum later moved into the refreshment rooms set up for this exhibition. The Department of Science and Art was also based in South Kensington and there is also the elaborate neo-gothic memorial to Prince Albert facing the Royal Albert Hall (N51.5016 W0.1776). The area as a whole is sometimes called "Albertopolis" after its founder, Prince Albert (1819-1861).

When you arrive at South Kensington tube station (District, Circle and Piccadilly Lines), turn right out of the subterranean ticket hall into a tunnel which was originally built for the International Inventions Exhibition in 1885, walk to the very end of the tunnel and go up the stairs. Turn right to go to the main entrance of the Science Museum (Figure 5). The Science Museum arose out of two neighboring museums on the other side of Exhibition Road founded in 1857, the South Kensington Museum and the Patent Office Museum which was taken over by the South Kensington Museum in 1883. Meanwhile there were efforts afoot to create a science museum. A major step in that direction was the 1876 Special Loan Exhibition of Scientific Apparatus held in the former refreshment rooms of the 1862 International Exhibition which were on the site where the museum now stands. When the new buildings of the Victoria and Albert Museum (as the South Kensington Museum was renamed in 1899) were formally opened in June 1909, the science collections were split off to form the Science Museum. The new building designed for the museum's collections was delayed by World War I and was not formally opened until 1928. Its architecture owes more than a little to the new department stores springing up around the country, notably Selfridge's in Oxford Street. The Centre Block of the museum was not completed until 1967 and the final stage of the museum's construction, the Wellcome Wing, was opened in 2001 (*36*). The museum can be seen as divided into three parts. The front part is mostly galleries devoted to specific subjects or themes with the exception of the interactive gallery "Launch Pad" on the third floor. The "Challenge of Materials" gallery on the first floor is perhaps the most chemistry-related of the current galleries and adult visitors will enjoy the elegance of the "Science in the 18th Century" exhibit which displays King George III's collection of scientific instruments on the third floor. Between these galleries and the Wellcome Wing, which is dedicated to contemporary science, is the large "Making the Modern World" gallery on the ground floor,which displays the icons of science and technology including the "Rocket" locomotive, the Apollo 12 capsule and a V2 rocket.

"Making the Modern World" also contains two much smaller objects which represent two important chemical breakthroughs made in London which can both be found in the low cases running down the middle of the gallery. One is a small bottle containing purple mauveine dye. In March 1856 during his Easter holiday from school, an 18-year old chemistry student at the Royal College of Chemistry in Oxford Street, William Henry Perkin (1838-1907), was attempting to synthesize quinine in his little laboratory at his parent's home at King David's Fort in the East End of London. Needless to say, his attempt failed, but he saw promise in the black gunk produced by his oxidation of (impure) aniline. He managed to extract a purple dye and after receiving an encouraging report from the dyers and cleaners Pullars of Perth, he decided to manufacture the dye with the help of his father, a carpenter and builder, and his elder brother. Mauve dye (as it was called from 1859) was short-lived; it was no longer made after 1873, but it was phenomenally profitable and Perkin was able to retire at the age of 35. More importantly, it launched an entire industry, the synthetic dye industry (which later became the organic chemical industry). The crucial watershed in this new industry was the commercial synthesis of the brilliant fast red dye alizarin. Perkin developed his own process for synthetic alizarin but had to share the credit (and the patent rights) with the German firm BASF and thereafter the Germans dominated the industry. Despite the wording on the label on the bottle ("Original Mauveine prepared by Sir William Perkin in 1856"), it was probably made for the lavish celebrations to mark the 50th anniversary of mauveine in 1906, celebrations which owed much to growing anxiety about Germany's growing lead in chemical innovation and hence the need to emphasize the British roots of the synthetic dye industry (*37*).

The second item in "Making the Modern World" is equally small and unpromising looking. It is a prototype electron capture detector made by James Lovelock (b. 1919) while he was working at the National Institute for Medical Research (NIMR) in Mill Hill, north London. Lovelock had initially trained as a chemist, but then moved into medical research. After leaving the NIMR in 1961, he became a freelance scientist and inventor and has become well-known as the co-proposer of the Gaia hypothesis. Gas chromatography had been developed by Archer Martin (1910-2002) and Tony James (1922-2006) at the NIMR in 1951, but the technique lacked sensitive detectors which could monitor the composition of the gas flowing out of the chromatograph. By the end of the 1950s, two excellent detectors had appeared, one was the flame ionization detector and the other was the electron capture detector (ECD) developed by Lovelock. The flame ionization detector was more general in scope, but the ECD was discovered to be wondrously sensitive for compounds containing halogen atoms. This made it immensely useful for the detection of pesticides containing chlorine (DDT, Lindane, Dieldrin, Aldrin, Endrin) and chlorofluorocarbons (CFCs). By chance while on holiday on the west coast of Ireland in 1967 Lovelock discovered to his great surprise that he could use the ECD to detect CFCs from the east coast of the USA, probably from leaking air-conditioning units in automobiles. His subsequent research on the worldwide distribution of CFCs, combined with the theoretical work of Sherwood Rowland 1927-2012) and Mario Molina (b. 1943) and the discovery of the ozone hole in Antarctica in 1985, led to a worldwide ban on the manufacture and use of CFCs.

Figure 5. The Science Museum, Exhibition Road.

The gallery also contains one of the most famous icons of modern science, the DNA model constructed in 1953 by James Watson (b. 1928) and Francis Crick (1916-2004) in Cambridge. What you see is not actually the original model but it is a careful reconstruction using the original metal plates cuts for their model which eventually found their way to the University of Bristol. Each of the metal plates represents one of the four bases of DNA, the pyrimidines cytosine and thymine and the purines adenine and guanine. If you look at the plates carefully you can see letters written on them such as T, G, C and B (which may stand for base). By the 1950s, biologists had become convinced that DNA must be the compound that transmitted genetic information from generation to generation. But how did it carry out this task? And what was its structure? It turned out that the answer to the second question provided the answer to the first one. The American chemist Linus Pauling (1901-1994) had proposed a helical structure for keratin, on the basis of work by the British X-ray crystallographer Bill Astbury (1898-1961) on wool, and in 1952 he argued that DNA must have a triple helix structure. Watson and Crick were convinced that Pauling was wrong and they were fortunate to be given the latest results of the X-crystallography of DNA carried out at King's College London in the Strand by Maurice Wilkins (1916-2004) and Rosalind Franklin (1920-1958). They began to realize that the bases must be paired which suggested both a double helix structure and a mechanism for replicating the DNA structure to create a new DNA molecule thus showing how DNA was transferred. Watson, Crick and Wilkins were awarded the Nobel Prize for medicine or physiology in 1962.

Round the corner from the Science Museum is Imperial College. Many of the older buildings of the college, including the Imperial Institute, were demolished in the 1950s and 60s. However, after protests were made, one of two clock towers of the Imperial Institute were retained as a free-standing building called the Queen's Tower. The institute had been founded in 1887 as a national gift to Queen Victoria on her Golden Jubilee, as an institution to promote the British Empire, especially in the form of scientific research to support its agricultural and industrial development, such as the study of rubber. On the left-hand side of Imperial College Road (formerly Imperial Institute Road) you can see the remaining wing of Aston Webb's chemistry and physics laboratories built for the Royal College of Science (which soon afterwards became part of the new Imperial College) in 1906. The elaborate façade is typical of the "Edwardian baroque" of this period and the shields celebrating great scientists are based on a similar idea at Hofmann's laboratory in Berlin built nearly forty years earlier. The chemistry department is still partly housed in this building as of 2014. On the corner of Imperial College Road with Exhibition Road, one can see two gas lamps, which are still in regular use. They can also be seen in other parts of central London, for example around Buckingham Palace and the Houses of Parliament.

Coming out of the Science Museum, one cannot overlook the Victoria and Albert Museum (always called the V&A) while walking along Exhibition Road. Directly opposite the Science Museum there is a splendid red brick building with a rather incongruous white neo-classical top which is now the Henry Cole wing of the V&A. However, it was built in the late 1860s as the Normal School of Science as a response to the building of massive laboratory buildings in Germany in Berlin, Bonn and Leipzig. Its design was based on the report on the laboratories in Bonn and Berlin by Hofmann who had just left London for Berlin, having relinquished the chair at Bonn to August Kekulé (1829-1896). The loggia, which dominates the neo-classical top, was designed for open-air chemical experiments and is based on a similar loggia in the Berlin laboratory building. The building was transferred from the Normal School's successor Imperial College to the V&A in 1978. The term Normal School comes from the French word for a college for teachers rather than implying any kind of eccentricity (or the lack of it). On the third floor of the V&A, you can see spectacular silver-plated copies of historic statues of animals made by the leading Victorian firm of Elkington, & Co. using the technique of electrotyping. In electrotyping, first developed in 1838 by the German physicist Moritz Hermann Jacobi (1801-1874), copper from an ingot is electrolytically transferred to a clay mould of the original object. The hollow copper copy thus formed can then be silver-plated (or gold-plated) if desired. At the entrance to the Silver Galleries, one can see a silver gilt leopard created by Elkingtons in 1884 from an original in the Imperial Russian collections. In Room 80, there is a set of three silver lions, copied from the originals which guarded the royal throne in Rosenborg Castle, Copenhagen, Denmark, made by Elkingtons in 1885.

Opposite the V&A on Cromwell Road (strictly speaking the V&A is in Cromwell Gardens) is the Natural History Museum. When Sir Hans Sloane's collection of antiquities and "modern curiosities" was purchased by the British government for the new British Museum in 1753, it included many natural history and geological specimens which were then increased by later acquisitions. When Richard Owen (1804-1892), the biologist who coined the word dinosaur, became superintendent of the newly created natural history department in 1856 he campaigned for a new building for his collections. A site was found in South Kensington, where the 1862 International Exhibition had just taken place. A veritable palace of natural history was designed by Captain Francis Fowke, who designed the Royal Albert Hall, and soon after his death, the design was taken over by Alfred Waterhouse, now famous for his neo-Gothic university buildings and laboratories. Owen retired when the building was completed in 1883. British Museum (Natural History) remained its official title until 1992 although it has been called the Natural History Museum for many years (*38*). In 1986 the Natural History Museum absorbed the neighboring Geological Museum, which had been founded in 1837 in Whitehall as the Museum of Practical Geology. Between 1851 and 1934, the museum was located between Jermyn Street and Piccadilly (where Waterstones now have their flagship bookstore) and it moved to Exhibition Road in 1935. In the grand entrance hall of the Natural History Museum one can see "Dippy," the replica of the *Diplodocus carnegii* skeleton unearthed in Wyoming in 1898 and displayed at the Carnegie Museum in Pittsburgh. The Scottish-born business tycoon Andrew Carnegie, having obtained the original for his new museum, had the copy made at the request of King Edward VII and it arrived at the Natural History Museum in 1905. However it may be moved when the new Hintze Hall is created. In the Vault one can see one of the finest examples in the world of alexandrite (also called cat's-eye), a form of the mineral chrysoberyl ($BeAl_2O_4$). It changes color depending on the type of light reflecting off it. In daylight, it is grass-green but under white tungsten light it is raspberry red. First discovered in the Urals by the Finnish mineralogist Nils Gustaf Nordenskiöld (1792-1866), it was named after the Tsesarevich Alexander Nikolaevich (later Alexander II) allegedly because it was discovered on his 21st birthday. As Henry Sowerby pointed out in 1850, the gem displays the two colors of the Russian Empire—red and green (*39*). The finest specimens, like those in the Natural History Museum, come from the island of Sri Lanka. The Vault also contains a rare Martian meteorite that weighs over a kilogram. It came from a shower of stones that fell near the village of Tissint in Morocco in July 2011. To minimize possible contamination, the meteorite is stored in a desiccator, which keeps it dry in a low-oxygen environment.

Walk down Cromwell Place opposite the main entrance to the Natural History Museum, turn rightwards into Onslow Place, right into Fulham Road and immediately left down Sydney Street, then across King's Road to Chelsea Manor Street almost opposite, you will reach Cheyne Walk, where the painter Joseph Mallord William Turner lived. Turn left and walk along Cheyne Walk into Royal Hospital Road, Chelsea and then first right into Swan Walk where the entrance to the Chelsea Physic Garden (N51.4850 W0.1628) is located. It is 20 minutes' walk from Sloane Square underground station (District and Circle Lines) or South Kensington underground station (District, Circle and Piccadilly Lines) and 30 minutes' walk from the museums in Exhibition Road. The Worshipful Society of Apothecaries (see Apothecaries' Hall) had a botanical garden for medicinal use (hence the "Physic") in Chelsea, then a rural area in 1673, and in 1722 the physician Sir Hans Sloane, who had become Lord of the Manor of Chelsea in 1713 (hence Sloane Square), gave the apothecaries a lease in Chelsea in return for a low rent and a supply of medicinal plants to the Royal Society. It was converted into a not-for-profit organization and opened to the public in 1983. The garden contains many plants of chemical and pharmaceutical interest. The main pharmaceutical garden is opposite the ticket booth at the entrance. It contains, among many other plants, autumn crocus (*Colchicum autumnale*), the source of colchicine, famously synthesized by Albert Eschenmoser (b. 1925) in 1959, the Madagascar Periwinkle (*Catharanthus roseus*, formerly *Vinca roseus*), the origin of the Vinca alkaloids used in cancer treatment, and *Ephedra altissima*, a source of ephedrine (although not the main one). In the hothouse behind the pharmaceutical garden there is a Cinchona tree (*Cinchona pubescens*), the source of quinine first planted in the garden in the 1680s. At the other end of the garden near the pond, there is a plot devoted to dye plants, including woad (*Isatis tinctoria*), madder (*Rubia tinctorum*) and indigo (*Indigofera tinctoria*).

Table 4. London Venues: Albertopolis

Venue	*Address*	*Opening Hours*	*Contact or Website/Other Information*
Science Museum	Exhibition Road	Daily 10:00 AM to 6:00 PM	(*40*); FREE (but charges apply for special exhibits)
Victoria and Albert Museum	Cromwell Road	Daily 10:00 AM to 5:45 PM (F until 10:00 PM)	(*41*); FREE
Natural History Museum	Cromwell Road	Daily 10:00 AM to 5:50 PM	(*42*); FREE (but charges apply for special exhibits)
Chelsea Physic Garden	66 Royal Hospital Rd.	Tu–F, Su 11:00 AM to 6:00 PM	(*43*); ADULTS £9.90

Wandering in Kew

Kew Gardens (more formally known as the Royal Botanic Gardens) are located at Kew (N51.4779 W0.2910) in south-west London, close to the British National Archives (formerly the Public Records Office). The gardens began as the summer residence of King George III and his family in the mid-18th century and a physic garden was established with the help of a gardener from the Chelsea Physic Garden. It was converted into a public garden in 1841 under pressure from the Royal Horticultural Society and placed under the energetic leadership of the botanist William Hooker (*44*). The best gate to enter the gardens is the Victoria Gate, which is close to Kew Gardens underground station on the Richmond branch of the District Line and the London Overground. Just follow the signs for the short walk to the gate. The two main attractions are the large Palm House and the Princess of Wales Conservatory, both easily accessible from the Victoria Gate. The Palm House, constructed between 1844 and 1848, is a greenhouse that was designed by Decimus Burton, who also designed the Athenaeum's building. It contains, among many other things, a rubber tree—Henry Wickham brought rubber tree seeds (actually nuts) to Kew from Brazil in 1876 (but they were not smuggled out as often claimed)—and the Mexican yam (*Dioscorea macrostachya*), which was the basis of Syntex Corporation's development of oral contraceptives in the late 1950s and early 1960s. The Princess of Wales Conservatory contains water lilies and well-known houseplants that come from the tropics including the Swiss Cheese Plant (*Monstera deliciosa*). One can also see Kew Palace where King George III was confined during his periods of insanity and the 163 foot high Pagoda which was built in 1762.The Jodrell laboratories were founded in 1877, funded by Thomas Jodrell Phillips-Jodrell, whose family owned the Twemlow estate in Cheshire where the Jodrell Bank radio telescope is now situated. The chemists Charles Frederick Cross (1855-1935) and John Bevan (1856-1921) first met here in the early 1880s and did their early research on cellulose and lignin, which was the basis of their development of viscose rayon. The original building was replaced in 1965 and it is now situated near the Aquatic Garden (and the Princess of Wales Conservatory). There are walking tours of the gardens and further information can be found on the website or by email (*45*). The Kew Observatory (more precisely the King's Observatory), is not in Kew Gardens, despite its name. It is located in the Old Deer Park next to Richmond underground station, but the building is not open to the public as it is now rented privately as offices. The observatory was opened in 1769 to enable King George III (who was interested in science) to observe the transit of Venus of that year. The first superintendent was Stephen Demainbray (1710-1782), the famous natural philosopher, astronomer and lecturer. The scientific instruments associated with Kew Observatory and Demainbray (and hence George III) can now be seen in the "Science in the 18th Century" Gallery at the Science Museum.

Down South

Just a few miles east of central London lies the royal borough of Greenwich which is home to the National Maritime Museum, the Queen's House, the Royal Observatory Greenwich and the Cutty Sark, known collectively as Royal Museums Greenwich, a collection of edifices spread from the Royal Museums Greenwich on Romney Road (N51.4812 W0.0052) to the Greenwich Observatory itself (N51.4769 W0.0005) in Greenwich Park. The simplest way to get to the Greenwich museums is to go to the Bank Docklands Light Railway (DLR) station using the Central, Northern or District Lines (the latter via the Monument station), and then getting the DLR to Cutty Sark station. However, I prefer to take the River Boat from the London Eye or Tower Pier to Greenwich Pier. As you arrive in Greenwich you'll see the towering masts of the Cutty Sark, one of the last of the ocean-going clippers of the 19th century (there is an entry fee). To reach the Royal Observatory, exit the DLR station and follow the curved row of shops to pass underneath a brickwork archway which brings you into College Approach, with the Cutty Sark on your left and continue straight ahead towards the globe-topped gates of the Old Royal Naval College. Turn right into King William's Walk and continue straight ahead until you reach Greenwich Park, with the National Maritime Museum on your left. For visitors arriving by boat, walk straight ahead with the Cutty Sark on your right and join King William's Walk. At the park gates take the diagonal path to the left and join the tree-lined avenue that takes you directly up the hill. King Charles II founded the Observatory (Figure 6) in 1675 in Greenwich in view of the Pool of London. The site had Royal connections, making it the obvious choice of location, especially since Greenwich was still in the countryside in the 17th century. The original building, with its beautiful Octagon Room, is called Flamsteed House, as it was John Flamsteed (1646-1719), a deacon from Derbyshire, who was made the first Astronomer Royal in 1675. The building was designed by Wren, who was an astronomer himself, with the help of Hooke.

For many years the main concern of the Observatory—as is now well known thanks to *Longitude* (*46*)—was the accurate mapping of the stars for navigation at sea through time keeping and repeated astronomical observations. These data formed the basis of most navigational charts and so it was decided, at an international conference in Washington DC in 1884, to adopt the Greenwich meridian (west-east line) as the prime meridian (zero degrees longitude),. Flamsteed himself is best remembered for his posthumous star catalogue, the *Historia Coelestis Britannica* (1725) and his numbering of the stars in the constellations from west to east, a system which is still used today. As London moved outwards and pollution from smoke and light sources increased, in 1957 the Royal Greenwich Observatory moved to Herstmonceux in Sussex, but it was eventually defeated by the British weather (*47*). The telescopes migrated south to La Palma in the Canary Islands in the 1970s while the Royal Greenwich Observatory itself moved to Cambridge, but it was finally closed in 1998. Meanwhile the old Royal Observatory had become a museum under the auspices of the National Maritime Museum and called the Royal Observatory Greenwich to distinguish it from the then still-existing scientific institution. The Royal Observatory also has a modern Astronomy Centre and the Peter Harrison Planetarium which has daily shows. It was opened in 2007 and it is London's only working planetarium as the London Planetarium at Madame Tussauds in Marylebone Road (founded in 1958) closed in 2006.

Figure 6. Left: Flamsteed House. The bright red Time Ball falls every day at 1:00 PM, signaling the exact time. Right: Straddling the Prime Meridian. Photographs by Mary Virginia Orna.

Of particular interest to chemists is the burning glass used by William Herschel to study the solar spectrum and thus discover infrared radiation in 1800. It is on display in the South Building (the prism he used is currently on display in the "Cosmos & Culture" Exhibition at the Science Museum). While in the South Building, one can also see a brass spectroscope made by the leading London instrument maker John Browning (1831-1925) after atomic spectroscopy was introduced in the 1860s. On the north site of the Observatory in the Equatorial

Building, under an onion-shaped dome, there is the Great Equatorial Telescope (a 28-inch achromatic refractor) which was initially used to study the spectra of certain stars, but was later used to measure the orbital period of stars within binary systems and hence determine their mass by the laws of gravitation. It was commissioned by William Christie, Astronomer Royal between 1881 and 1911, and was completed in 1893. The objective lens was designed to be used both as a visual telescope and a photographic instrument. The telescope, which was constructed by the famous firm of Howard Grubb & Son, remains Britain's largest refractor (although much smaller than the 40 inch refractor of the Yerkes Observatory in Wisconsin). It was based at Herstmonceux from 1957, but was retired from active service and returned to Greenwich for educational use in 1971. It is possible to view through this telescope if you sign up for one of the nighttime events, but I have to say from personal experience that the optics of the objective lens are not as good as those of modern amateur telescopes. While in the Meridian Observatory, make sure you see the splendid Airy Transit Circle, which came into service in 1851 and was designed by George Biddell Airy, the Astronomer Royal between 1835 and 1881. Its cross-wires mark the exact prime meridian. A transit circle is used to determine the exact position of stars.

Down the hill from the Royal Observatory is the National Maritime Museum which is housed in buildings that partly date back to the Royal Palace at Greenwich in the 17th century and which formerly housed the Royal Hospital School. The museum itself stemmed from an earlier gallery of naval art in the Royal Naval College and it was founded in 1937 largely at the behest of the wealthy ship-owner Sir James Caird (*48*). As the world's largest maritime museum, it covers all aspects of seafaring history from life at sea, ship technology, trade, exploration, art and warfare. Opposite the museum you can see the splendid former Royal Naval College (now housing the University of Greenwich), originally a hospital for seafarers, and designed at the end of the 17th century by Wren: you can see the resemblance to the dome of St Paul's Cathedral in the twin cupolas.

The Horniman Museum (N51.4413 W0.0606) in south London, between Dulwich and Forest Hill, is not a conventional science museum, but it has large anthropological and natural history collections that are of scientific interest. It also has a world-famous collection of musical instruments. The museum was founded to house his collections in 1901 by Frederick Horniman and occupies a striking Arts and Crafts building which looks like a fantasy railway station. The Horniman family had made its money from its tea business. The museum and the extensive gardens are open every day and are free; there is a charge for the aquarium. The Horniman Museum (Figure 7) is not served by the underground system but the railway station at Forest Hill can be reached from London Bridge railway station (which can itself be reached using the Jubilee or Northern underground lines or by walking over London Bridge from the Monument). It is about a 15-minute train journey and another ten minutes' uphill walk from the station to the museum.

On the outskirts of London, traditionally in Kent but officially now part of Greater London, is Down House (N51.3304 E0.0528) the home of Charles Darwin. To get to Down House, take the train from Victoria to Bromley South and then get the 146 bus: it is too far to walk. Darwin—keen to move out of London and find a larger home for his family—bought Down House in 1842. The house, which had been built around 1780, was not particularly attractive nor in a beautiful spot, but it suited Darwin's rather reclusive nature and the family stayed here until the death of Emma Darwin in 1896, Darwin himself having died fourteen years earlier. It was turned into a museum in 1929 and having passed through the hands of the British Association for the Advancement of Science and the Royal College of Surgeons, it was taken over by English Heritage in 1996. In Darwin's study you can see the chemical apparatus he used.

Figure 7. The Horniman Museum. Photograph by Mike Peel, under license from Creative Commons.

Up North

The Alexander Fleming Museum is located in Alexander Fleming's (1881-1955) laboratory at St Mary's Hospital Paddington (N51.5174 W0.1725) where he first discovered the antibiotic powers of *Penicillium notatum* mould in a petri dish he had failed to wash up in 1928, although the isolation and use of pure penicillin as an antibiotic lay another fifteen years or so into the future. The laboratory has been restored to show the cramped conditions under which Fleming worked. There is also a display and video about the history of penicillin. The museum was declared an International Historical Chemical Landmark by the American Chemical Society in 1999 (*49*). The hospital is near Paddington railway and underground station, but it is not near any of the other sites on the tours above.

The observatory of the Hampstead Scientific Society is one of London's less known scientific features. It has a professional looking white dome and two 6" telescopes including an antique Cooke refractor (the Cooke refractors had a similar reputation to Clark refractors in the USA). It is open to the public for observing on clear evenings every Friday and Saturday between 8 and 10 PM Greenwich

Mean Time (hence an hour later after the end of March) and for observing the sun every clear Sunday between 11 AM and 1 PM. The observing season is usually mid-September to mid-April, but it is sometimes extended into May. Contact the Hampstead Scientific Society beforehand to check on times (*50*). It is located in Lower Terrace, Hampstead (N51.5600 W0.1807), near Hampstead Heath. It is a 10 minute walk from Hampstead underground station.

Table 5. London Venues. Outside Central London

Venue	*Address*	*Opening Hours*	*Contact or Website/Other Information*
Kew Gardens	Victoria Gate, Kew	Daily 9:30 AM to 6:00 PM	(*51*); ADULTS £15
Royal Observatory Greenwich	Blackheath Avenue, Greenwich	Daily 10:00 AM to 5:00 PM	(*52*); ADULTS £8.50
National Maritime Museum	Park Row, Greenwich	Daily 10:00 AM to 5:00 PM	(*53*); FREE
Horniman Museum	100 London Road, Forest Hill, London	Daily 10:30 AM to 5:30 PM	(*54*); FREE (Aquarium £5)
Down House	Luxted Road, Downe, Kent	Daily 10:00 AM to 6:00 PM	(*55*); ADULTS £10.30
Alexander Fleming Museum	St. Mary's Hospital, Praed St.	M–Th 10:00 AM to 1:00 PM and by appointment	(*56*); ADULTS £4
Hampstead Scientific Society Observatory	Lower Terrace, Hampstead	Variable, according to the season; closed summers	(*57*); FREE

Oxford

The famous university town of Oxford, can be reached in about an hour from London by train from Paddington or more inexpensively by coach from Marble Arch coach stop, near Marble Arch tube station, taking either the Oxford Bus X90 or the Oxford Tube (the two stops are next to each other), taking just under two hours. Driving in Oxford is very complicated because of the one-way system and is not recommended. However, there are "Park and Ride" car parks on the outskirts and there are frequent buses into the city. The Thornhill Park and Ride (N51.7629 W1.1811) is the most convenient for drivers coming from London on the M40. For centuries, since the university was first formed in the 12th century, Oxford was a market town and a university town. There was no industry to speak of, although there was a tradition of brewing, partly because the standard lunch in the colleges was bread, cheese and (weak) beer. "Gown" (the university) dominated "town" until well into the 19th century. The university itself was largely clerical in nature—all the fellows had to be unmarried clergymen—and the emphasis was on training men (and it was only men until the 1870s) for the Church and State. This situation was radically changed in the early 20th century when William Morris (later Lord Nuffield)—not to be confused with the other William Morris, the founder of the arts and crafts movement—founded Morris Motors. Morris, like Henry Ford but on a smaller scale, had the idea of mass-producing cars for the middle classes, although car ownership remained a rarity in Britain until the 1960s. He established his factory at Cowley on the eastern edge of Oxford in 1913 and his firm became a major automobile manufacturer in the interwar period. After World War II, Morris Motors merged with its rival Austin Motors and became part of British Leyland in 1968. However these mergers failed to meet the competition from abroad (and foreign makers based in Britain) and the Cowley plant was taken over by BMW, who still make the new-version MINI there. Meanwhile, the university had begun to teach science as an undergraduate degree after 1850 and it is now completely co-educational and offers a wide range of courses. By the 1960s, in contrast to Cambridge, Oxford had become a typical industrial south Midland town with a few colleges added on rather than a bucolic haven of dreaming spires. With the decline of manufacturing and the growth of the university (for example the Said Business School which can be seen on the left when walking from the train station), the tide may be turning in the university's favor again.

The starting point for our tour, the stone tower called Carfax (N51.7520 W1.2579), has nothing to do with science at all, but it was the center of the town in medieval times. The neighboring Swindlestock Tavern (long vanished) was the starting point in February 1355 for the two-day riot between the students and the townspeople called the St. Scholastica's Day Riot which left over ninety people dead. The tavern is commemorated by a plaque on the bank to the north of Carfax. Carfax is a fifteen minute walk from Oxford railroad station via Park End Street, New Road and Queen Street or a twenty minute walk from Gloucester Green coach station via George Street, then turning right into Cornmarket. Walk down the High Street, which is facing you if you have your back to Carfax, to the Botanic Gardens, which are on the right just before Magdalen Bridge. About half way down the street, on the right hand side, opposite the entrance to All Souls' College, you can see the plaque on the wall of University College marking the site of Robert Boyle's laboratory between 1655 and 1668 (Figure 8). Alternatively, you can get the 3, 5, 13 or 280 buses from the railroad station to the garden. The Botanic Garden is part of Oxford University and was founded as a physic garden in 1621 by Henry Danvers, 1st Earl of Danby. The Botanic Garden is located at a beautiful spot with the River Cherwell on one side, Christ Church Meadows to the south and Magdalen College tower to the north. It contains a walled garden, the lower garden and the greenhouses. Like most botanical gardens, they contain many plants of chemical interest including yew (the oldest tree in the garden), snowdrops which contain galantamine used to treat Alzheimer's disease, sweet wormwood (*Artemisia annua*) used as an antimalarial in the form of artemisinin, and goat's rue (*Galega officinalis*) which contains guanidine, as well as familiar commercial plants such as coffee, cocoa and ginger.

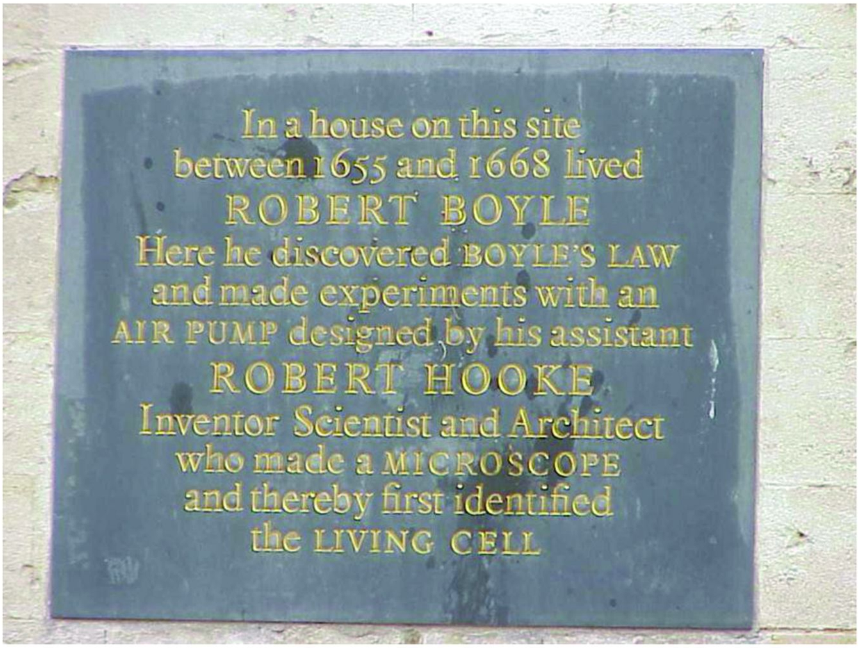

Figure 8. Site of Discovery of Boyle's Law, Oxford. Photograph by James Marshall.

If you walk out of the Botanic Gardens and walk along the High Street on the north side, you pass a shop currently called Fitrite which has a plaque commemorating the beginning of Morris Motors as a bicycle repair shop here in 1900. Opposite the shop is the Examination Schools where Oxford University students take their "finals" in May and June—traditionally, British students have only been graded on the basis of these examinations at the end of their course—wearing a compulsory black and white outfit called *sub fusc*. Walking down the High Street we reach the University Church of St. Mary the Virgin, then briefly turn right into Catte Street to see the splendid Radcliffe Camera which was once a science library but now is part of the Bodleian Library. Continuing along the High Street, we arrive at Turl Street with Exeter College, the former college of Nevil Sidgwick (1873-1952), on the corner. Turning north up "The Turl" we arrive at Jesus College on the left just before Broad Street. For over a century much of the chemical research at Oxford was carried out in laboratories housed within individual colleges rather than centralized university laboratories. This is remarkable when one bears in mind that before the 1960s the colleges had only a couple of hundred students (at most), of which perhaps fifteen or twenty were chemistry undergraduates. At Oxford, undergraduate chemists do a one-year research project called the "Part II," so at any one time a college might have three or four Part II chemists working in the laboratory and hardly any postgraduate chemists, as PhDs were very rarely taken in the British educational system before the 1950s. The movement towards college laboratories began in 1848 when Charles Daubeny (1795-1867), the Aldrichian Professor of Chemistry since 1822, grew tired of the almost medieval basement laboratory in the Old Ashmolean Museum and had a new laboratory constructed at Magdalen College in 1848 (*58*). Christ Church had already built the Lee Building for both chemistry and anatomy in 1766 and the chemists acquired the whole building in 1860 when the anatomists moved to the new University Museum (see below). Soon after the science degree was introduced in 1850, Balliol College also set up a laboratory in a basement, and Trinity College shared this laboratory after 1879. Queen's College set up its laboratory in 1900 and Jesus College in 1907-8. All the college laboratories did research in physical chemistry, broadly defined—including the important work of Cyril Hinshelwood (1897-1967) on gas kinetics in the Balliol-Trinity laboratory—except at Queen's where Frederick Daniel Chattaway (1860-1944) carried out organic chemical research until his retirement in 1934. He authored a paper crucial for the development of DDT. When the new physical chemistry laboratory in the Science Area (see below) was opened in 1941, Hinshelwood moved his team from the Balliol-Trinity laboratory and the era of the college laboratories was almost over, the last one—at Jesus College—closing in 1947. All the old laboratories have been converted to other uses—the Lee Building is now an extension of the Senior Common Room (the Oxford equivalent of the faculty club)—and only the one at Jesus College can be seen from the outside by visitors. Go through the first and second quadrangles to the third quadrangle. Facing you is a block that was completed in 1908. The chemistry laboratory was on three floors on the west wing, to the left of the elaborate gateway (*59*). For nearly all of its existence, it was run by David Leonard Chapman (1869-1958), a physical chemist who was interested in the kinetics of gaseous reactions and in particular the theory of gas explosions. The wing was converted into student accommodation after the laboratory closed.

Coming out of Jesus College we turn left into Broad Street (which is indeed very wide) and then turn right to go to the Museum of the History of Science, just before the striking busts (often thought erroneously to be those of Roman emperors) in front of the Sheldonian Theatre, designed by Wren and built in the 1660s. Although the museum itself was only opened in 1924, it is located in the Old Ashmolean Museum which was opened as the first public museum in 1683 (*60*). It then housed the collections of Elias Ashmole (1617-1692) who in turn acquired much of his material from the pioneering botanists John Tradescant senior and junior. At first, the focus of the museum was teaching science with lectures on the ground floor and a chemical laboratory in the basement. Gradually however, the focus of the museum shifted to archeological antiquities and the Ashmolean Museum was moved to its present site in Beaumont Street in 1894 to give it more space. After being used as offices by the *Oxford English Dictionary*, the original building was converted into the Museum of the History of Science. Buses are not frequent along this route so the only alternative to walking is a taxi cab. The top floor of the museum contains the mathematical collections (including its superb collection of astrolabes). The basement covers chemistry, physics and medicine and contains the blackboard Einstein wrote on when he visited Oxford in 1931. It also houses the Marconi radio collection donated to the museum in 2004. The highlights of the collection including a group of orrerys (clockwork planetary models), King George III's silver microscope, the Fromanteel clock, an early pendulum clock, and John Dee's magic tablet for communicating with angels are found on the middle floor.

Many of the university laboratories in Oxford are in or near South Parks Road, which (as its name implies) lies south of the University Parks, an area known as the "Science Area." If you walk up Parks Road which is near the Museum of the History of Science, you pass Wadham College on the right, the home of John Wilkins' philosophical club in the 1650s (which was the forerunner of the Royal Society) and you soon reach the corner with South Parks Road on the right. To the left of this junction is a white cottage that was previously the home of the chemical crystallography department. The imposing building on the northern corner of South Parks Road is the Radcliffe Science Library which is the successor (as a science library) of the Radcliffe Camera. Sir Henry Acland (1815-1900) became the Librarian of the Radcliffe Camera in 1851 and persuaded the trustees to allow the books to be moved to the new University Museum. As scientific literature expanded, the books and journals outgrew their accommodation and a new library building on South Parks Road, funded by the Drapers' Company (a guild of the City of London), was opened in 1901. As you walk down South Parks Road on the on the same side of the road you pass a rubble-faced building which looks rather like a crusader fortress. This is the inorganic chemistry laboratory (N51.7578 W1.2554), dating from 1878 and extended in 1957 (*61*). There are three plaques on the right-hand side of the archway. These are RSC Chemical Landmark plaques: the first to commemorate the invention of the glucose detector (by Allen Hill and his team) in 1982, the second for Dorothy Crowfoot Hodgkin (1910-1994), 1964 Nobel Laureate in Chemistry for X-ray crystallography (she worked in this building but also elsewhere in the Science Area, including the University Museum, see below) and the third plaque is for the development of the lithium ion battery by the American solid-state physicist John Goodenough (b. 1922) in 1980 when he was professor of inorganic chemistry. On the other side of the road is Rhodes House, the headquarters of the Rhodes Trust, which was opened in 1928 to mark the 25th anniversary of the Rhodes scholarships. It was designed by the Sir Herbert Baker, who worked extensively in South Africa and India, hence the colonial appearance of the building. Carrying on down the road we reach the Queen Anne style building which is the Dyson Perrins laboratory (named after philanthropist who funded it, a member of the Worcester Sauce family and always called the "DP") built in 1916 for William Henry Perkin Jr. (1860-1929) One can see next to the main entrance the RSC Chemical Landmark plaque commemorating the work of Sir Robert Robinson (1886-1975) among others. The building was closed as a chemical laboratory in 2004 and its research activities moved to the new Chemistry Research Laboratory across the road, which is used by the entire chemistry department. Finally we reach the Physical Chemical Laboratory which stands opposite the DP across an entrance road. This laboratory was funded by Lord Nuffield and when it was opened in 1941, physical chemistry—the predominant subdiscipline at Oxford since the late 19th century—became centralized.

Returning to the corner of Parks Road and South Parks Road and continuing north, we reach the neo-gothic University Museum. To the south of the museum, nestled into the Radcliffe Science Library is a copy of the "abbot's kitchen" at Glastonbury. Opened in 1860, this was the first university chemical laboratory in Oxford since the Ashmolean Museum in 1683. It is still used by the inorganic chemical laboratory and part of it is now a coffee room for staff. The University Museum of Natural History (Figure 9), completed in 1861, was intended to be the center of scientific research in Oxford following the establishment of a science degree (which nonetheless remained a Bachelor of Arts degree) in 1850, but it was soon supplanted by the college laboratories and more specialized departmental buildings such as the Clarendon Laboratory. It thus became a museum which specialized in natural history, acquiring the Tradescants' natural history collection from the Ashmolean Museum. The famous debate on Darwin's theory of evolution between Bishop Samuel Wilberforce and Thomas Huxley took place in the museum in June 1860, during the meeting of the British Association for the Advancement of Science in Oxford. However it was an exchange of views rather than a formal debate and Joseph Hooker (son of William Hooker) also played an important role (*62*). The most famous exhibit in the museum is the dodo (of which only the head and foot still exist) and which is the origin of the dodo in *Alice's Adventures in Wonderland*. It also has a collection of dinosaurs, and four are from Oxfordshire including two complete skeletons—one of which was found only a mile from the museum in 1870. Next to the museum is the Pitt Rivers Museum which moved to Oxford in 1884 after originally being in South Kensington. The military officer Augustus Lane Fox (1827-1900), who adopted the surname Pitt Rivers after receiving a large legacy in 1880, had the idea that human development could be studied using the theory of Darwinian evolution. One could trace the line of one particular technological development by assembling a line of more and more sophisticated artifacts, a concept which still subtly influences museology a century and a half later. Furthermore as each human group will follow similar lines of development, according to Pitt Rivers, one can fill any gaps in the historical record by taking a contemporary artifact from a less advanced group. So he assembled hundreds of artifacts from all over the world relating to one particular field of development (for example musical instruments) rather than following the then standard practice of only collecting the rarest or most beautiful objects. He gathered 18,000 objects and the museum now has over half a million. Interesting collections include musical instruments, textiles and weapons.

If you carry on up Parks Road beyond the University Museum (N51.7587 W01.2555), you will see on the museum's left-hand side through a gateway a modest red brick building. This is the original physics laboratory in Oxford (and one of the earliest in the country), the Clarendon Laboratory, completed in 1872. While it never had the reputation of the Cavendish Laboratory in Cambridge, it was a center for German émigré physicists—including Francis Simon, Fritz London and Nicolas Kurti—in the 1930s and 1940s thanks to its director, the Anglo-German physicist Frederick Lindemann (1886-1957), later Viscount

Cherwell. Even Albert Einstein (1879-1955) was briefly in Oxford before moving to Princeton. It was also the starting point for Britain's atomic bomb project codenamed "Tube Alloys" which was later subsumed into the Manhattan Project. The building is now used by the earth sciences department. Next to the entrance is a RSC Chemical Landmark plaque commemorating the work of Harry Moseley (1887-1915) on the X-ray spectra of the elements (and hence the concept of atomic number) in 1913 just a year before he was killed in action at Gallipoli.

Figure 9. University Museum of Natural History, Oxford. Photograph by Alan Ford, under license from Creative Commons.

Retracing our steps down Parks Road, we find an alleyway on the southern side of Keble College, easily recognized by its polychromic brickwork, which goes through to St. Giles'. On the opposite side of the road is a small public house (bar) called the Eagle and Child, the favorite haunt of the "Inklings," a literary group which included J. R. R. Tolkein and C. S. Lewis, who nicknamed the hostelry the "Bird and Baby." Cross over to the Eagle and Child and, suitably refreshed, continue north on St. Giles' (which becomes the Woodstock Road) for about five minutes until you see the octagonal tower of the Radcliffe Observatory. The Radcliffe Observatory was built at the suggestion of the Savilian Professor of Astronomy Thomas Hornsby (1733-1810), following the transit of Venus in 1769, and was opened in 1773 but not completed until 1794. The final design by James Wyatt is based on the Tower of the Winds in Athens and is surmounted by a sculpture of Atlas holding up the world. The observatory was also used for meteorological observations for many years and the measurements made here play an important role in our understanding of climate change. The observatory was eventually moved to Pretoria in South Africa in 1934 and thanks to the generosity of William Morris, Lord Nuffield, the building became the Nuffield Institute for

Medical Research within the grounds of the neighboring Radcliffe Hospital. When the institute moved with the hospital to a new site in Headington outside the center of Oxford, the building was taken over by Green College which is now Green-Templeton College and is used as a common room. However visitors can still see the outside of the building, which is in fact visible from Woodstock Road. We can now walk back down the road to George Street (for the coach station and the railway station). To get to the station, go down George Street, continue along Hythe Bridge Road (over the Castle Mill Stream) and Park End Street.

Table 6. Oxford

Venue	*Address*	*Opening Hours*	*Website/Other Information*
Botanic Garden	Rose Lane	Daily 9:00 AM to 5:00 PM	(*63*); ADULTS £4.50
Jesus College	Turl St.	Daily 2:00 PM to 4:30 PM	(*64*); ADULTS £2
Museum of the History of Science	Broad Street	Tu–F 12:00 PM to 5:00 PM; Sa 10:00 AM to 5:00 PM; Su 2:00 to 5:00 PM	(*65*); FREE
University Museum of Natural History	Parks Road	Daily 10:00 AM to 5:00 PM	(*66*); FREE
Pitt Rivers Museum	South Parks Rd.	Tu–Su 10:00 AM to 4:30 PM; M 12:00 to 4:30 PM	(*67*); FREE

Conclusion

My current job is to write applications for grants from national funding bodies and philanthropic institutions (such as the Leverhulme Trust). For many years now, the state has emphasized the need for research to be relevant and currently this is ensured by applicants writing “impact statements” which show how the proposed research will benefit the economy, society or environment by their “impact.” The aim is well-intended, but one wonders just how much of this planned benefit actually happens in the end. Conversely scientists often claim that “blue skies” research, carried out with no intended benefit in mind, can bring about unexpected blessings. The problem is that they always bring up the same time-worn (and often doubtful) examples as if they were representative of all such research. One thinks in particular of the alleged comment of Faraday that electromagnetic induction was like a newborn baby (the phrase actually originated with the more poetic Benjamin Franklin). Even if we accept that very little blue skies research actually produces something useful in the long term or even that directed research does so more often (and perhaps more quickly), one can still be concerned by the limitations placed on science (and scientists) by modern funding methods.

It is striking how in the past many scientists in London and Oxford either were working without state funding (or indeed any kind of funding) or if they were working for the state, they were able to carry out their research without the need to justify it in great detail. One of the best examples of the latter was James Lovelock (b. 1919), who was working (indirectly) for the state at the National Institute for Medical Research, but under Sir Charles Harrington's benevolent regime he was able to continue his work on gas chromatography on the basis of a brief conversation with Harrington. The college laboratories in Oxford flourished without any significant amount of state funding. John Harrison (1693-1776) may have been seeking to win a state-funded prize, but he built his chronometers free from any state direction (and indeed in the face of opposition from the state's experts). Furthermore, many scientists in London (and Oxford) were either self-funded (perhaps from the proceeds of publishing or consultancy) or amateurs in the true sense of that term. One thinks of amateur chemists such as the discoverer of niobium Charles Hatchett (1765–1847) of Hammersmith who was a coach-builder by day or his contemporary the independently wealthy William Hyde Wollaston (1766-1828) of Fitzrovia who discovered rhodium and palladium. Joseph Priestley (1733–1804)—who probably discovered oxygen in 1774 at Lansdowne House (now demolished, the site is now the GlaxoSmithKline head office) in Berkeley Square before leaving to do more experiments at his home in Calne, Wiltshire—was, as a teacher, librarian and clergyman, also an amateur chemist. Randal Thomas Mowbray Rawdon Berkeley (1865–1942), 8th Earl of Berkeley, a physical chemist, built a laboratory at his home at Foxcombe near Oxford in 1898, having previously used the laboratory at Christ Church. Lord Rayleigh, a landowner who lived (and worked) in Terling, Essex, fifty miles from London, made many advances in physics and co-discovered the first noble gas, argon. This was even more the case for astronomy. George Parker, 2nd Earl of Macclesfield (c. 1697-1764), set up an observatory and a laboratory at his seat Shirburn Castle, just outside Oxford, in 1739. Andrew Ainsley Common (1841-1903) was a sanitary engineer, but in 1879 built a 36-inch reflector at his home in the London suburb of Ealing which was one of the largest telescopes in the world at the time and one of the first to be used for astrophotography—it was later moved to the Lick Observatory in California. Hugh Percy Wikins (1896-1960), a civil servant, produced a famous map of the moon in 1946 at his home in Bexleyheath on London's border with Kent. Other scientists have kept their independence by earning money from their activities, including William Crookes (1832-1919), the editor of *Chemical News*, who had a laboratory in his home in Kensington Palace Gardens and the independent chemist Oswald Silberrad (1878-1960) built a laboratory for his consulting activities at his home in Buckhurst Hill, on the border between Essex and London, in 1907, which he later moved to Dryad's Hall in nearby Loughton. One might argue that such independence is outdated in an era of "big science," but Lovelock, who has remained an independent researcher, and one of world's leading supernovae hunters, Tom Boles, is an amateur who lives at Coddenham, Suffolk, eighty miles north-east of London. While state funding may be essential for space telescopes and hadron colliders, one cannot help wondering if this loss of independence and the ever-increasing demand for relevance will harm science in the long term, even if there are short-term benefits for society.

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Chapter 5

Displaying Science in Context at the Royal Institution of Great Britain

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Over the last two centuries the Royal Institution has been home to eminent scientists whose discoveries have helped to shape the modern world. But just as importantly it has shared this work with a wide public audience and continues to encourage people to think more deeply about the wonders and applications of science.

Introduction

There can be few buildings in the world with a floor area of around 3,000 m^2 where so many chemical and scientific discoveries have been made than the Royal Institution. Located behind its Corinthian columned façade (Figure 1), erected in the 1830s and dominating the northern end of Albemarle Street in the Mayfair district of London, the laboratories of the Royal Institution have been there since shortly after its foundation in 1799. In this building, figures such as Humphry Davy (1778-1829), Michael Faraday (1791-1867), John Tyndall (c. 1822-93), James Dewar (1842-1923), William Henry Bragg (1862-1942), William Lawrence Bragg (1890-1971), and, more recently, George Porter (1920-2002) have lived, researched and lectured. Furthermore, the Royal Institution has served as a model for other institutions around the world, most notably the Smithsonian Institution in Washington. James Smithson (1764-1829) was an early Proprietor of the Royal Institution and he seems to have had its aims in mind when he drew up his will that would establish the Smithsonian.

In Science History: A Traveler's Guide; Orna;

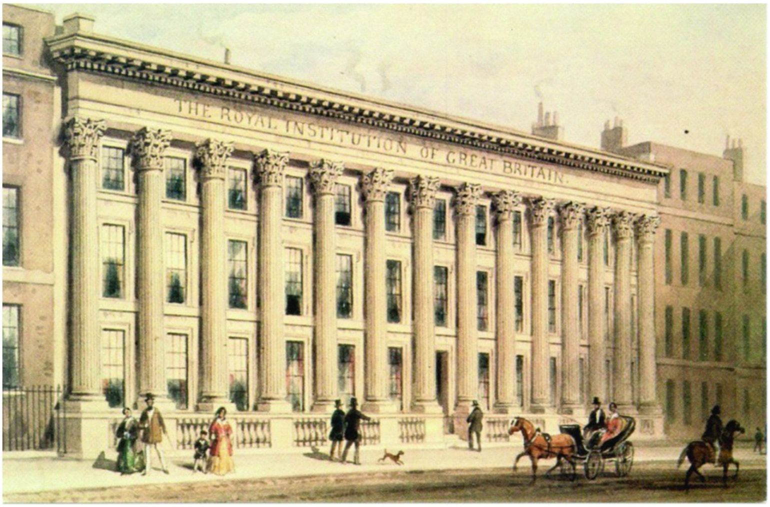

Figure 1. Watercolor by Thomas Shepherd of Royal Institution's Façade Built in the Late 1830s and Designed by Lewis Vulliamy.

Because of the significance of its heritage, the Royal Institution has a modern display, occupying most of the lower ground floor, of many original pieces of apparatus and chemical samples – including the first specimen of benzene made by Faraday in 1825. One of the heritage strengths of the Royal Institution is that every object, sample, manuscript, book, image and so on was created or purchased for use in the building and has been retained on site ever since. This is what distinguishes the Royal Institution from those museums that display important and significant scientific objects, but where they are necessarily separated from the original context of their creation and use. Furthermore, many of the objects displayed, such as Davy's miners' safety lamp (Figure 2), Faraday's electro-magnetic induction ring, or the first model of lysozyme, count as among the most iconic pieces of scientific apparatus ever made. They are on par with Galileo's telescope in the Museo Galileo, Florence, or Newton's reflecting telescope in the Royal Society, London.

While it might seem strange to modern eyes that the Royal Institution continues to exist in the midst of one of the most fashionable and wealthy areas of London, in the 19th century it was one of a number of scientific institutions in the district. At the time of the its foundation the Board of Agriculture (where Davy lectured on agricultural chemistry for ten years) was in Sackville Street a couple of blocks to the east. By the middle of the century the Royal College of Chemistry was located to the north in Oxford Street, while to the south were the School of Mines and the Geological Museum in Jermyn Street. These institutions later moved to South Kensington to form the core of Imperial College and part of the Natural History Museum. To the east was and is Burlington House, home to many of the leading learned scientific societies.

Figure 2. Oil Painting by Henry Pickersgill (after Thomas Lawrence), 1831, of Humphry Davy with Miners' Safety Lamp.

History

The Royal Institution of Great Britain has a rich history which is documented on its website (*1*) and in the literature listed in the "Further Reading" section. It was formally founded at a meeting held on 7 March 1799, at 32 Soho Square, the London house of the President of the Royal Society, Joseph Banks (1743-1820). Its founding took place against the background of the war with France (then in its sixth year) and the increasing industrialization that had occurred in Britain during the preceding century. The war, which would continue for another sixteen years, meant that Britain had restricted access to Continental markets and was forced to rely on its own resources. To help overcome this problem, it was initially envisaged that the Royal Institution would provide access to scientific and technical knowledge, through lectures, to a largely aristocratic and upper middle class audience with the aim of applying that knowledge for practical purposes. Furthermore, it was seen as a place where scientific knowledge could be practically applied to agricultural improvement, industrialization, and the consolidation of the Empire, the latter a particularly important consideration for Banks. These aims, in turn, encouraged those who had such interests to join: the early membership of the Royal Institution shows a strong presence of large landowners, military men, and those who worked in the colonial service such as the East India Company.

At the initial meeting in Banks's house, a list of fifty-eight names was read of gentlemen who had agreed to contribute fifty guineas (21 shillings; a pound is 20 shillings) each to be a Proprietor of a new

> *Institution For diffusing the Knowledge, and facilitating the general Introduction, of Useful Mechanical Inventions and Improvements; and for teaching, by Courses of Philosophical Lectures and Experiments, the application of Science to the common Purposes of Life* (*2*).

These aims were in contrast to those of the Royal Society, the meetings of which were restricted to their Fellows and their few guests to hear learned papers. Furthermore, the Royal Society did not have a laboratory, which would be a central feature of the Royal Institution. Banks, who generally opposed the forming of new scientific bodies, actively supported the establishment of the Royal Institution to do things that were not deemed appropriate to the Royal Society.

During the summer of 1799 the Royal Institution acquired 21 Albemarle Street, where it remains. Originally a townhouse that had been built in stages during the 18th century, much construction work was required to convert it into a scientific institution with lecture rooms, laboratories, display areas, libraries, offices, etc. Nevertheless, just over a year after its founding, the first Professor of Chemistry, Thomas Garnett (1766-1802), delivered on 11 March 1800 the first of what now exceeds 60,000 lectures to have been given in the Royal Institution. Following tensions within the Royal Institution, Garnett resigned in June 1801 and was replaced by Thomas Young (1773-1829), who, by all accounts, was not a particularly effective lecturer.

Young had developed an early form of the wave theory of light that incurred the displeasure of the radical Whig lawyer and politician Henry Peter Brougham (1778-1868). In his review of one of Young's papers that had been read to the Royal Society, Brougham attacked both Young and what he took to be the lack of seriousness in the audience of the Royal Institution, especially owing to the presence of women at lectures:

> *We demand, if the world of science, which Newton once illuminated, is to be as changeable in its modes, as the world of taste, which is directed by the nod of a silly woman, or a pampered fop? Has the Royal Society degraded its publications into bulletins of news and fashionable theories for the ladies who attend the Royal Institution* (*3*)?

Brougham missed the point since, unlike the Royal Society which did not admit women to its Fellowship until 1945, the Royal Institution from its inception was intended for women as well as for men.

One of the sources of tension at the Royal Institution was the appointment in February 1801, of the twenty-two-year-old Humphry Davy as lecturer in chemistry whom Garnett clearly saw as a rival. Davy, born in Penzance, the son of a woodcarver, was by the end of the 1790s working in the Medical Pneumatic Institution in Bristol, run by Thomas Beddoes (1760-1808). The Medical Pneumatic Institution had been funded by subscriptions, some very generous, to support research into whether the new gases (or airs as they were called) discovered during the latter half of the 18th century had any therapeutic properties, especially in curing, or at least mitigating, consumption. Alas, such expectations were not met, but Davy did discover the physiological action of nitrous oxide (laughing) gas. As well as working and writing on gases, Davy also undertook very early electrical researches following the announcement, right at the end of the 18th century, of the invention by Alessandro Volta (1745-1827) of what Davy would shortly call the electric battery. Such work made Davy's name in England and contributed significantly to his move to the Royal Institution. Evidence of the way he and laughing gas captured the public imagination can be found in the famous caricature by James Gillray (1757-1815) (Figure 3). In it Garnett is portrayed administering the gas to the Royal Institution's Treasurer John Hippisley (1748-1825) with somewhat unfortunate results behind, while a slightly demonic Davy watches with a pair of bellows poised for further action.

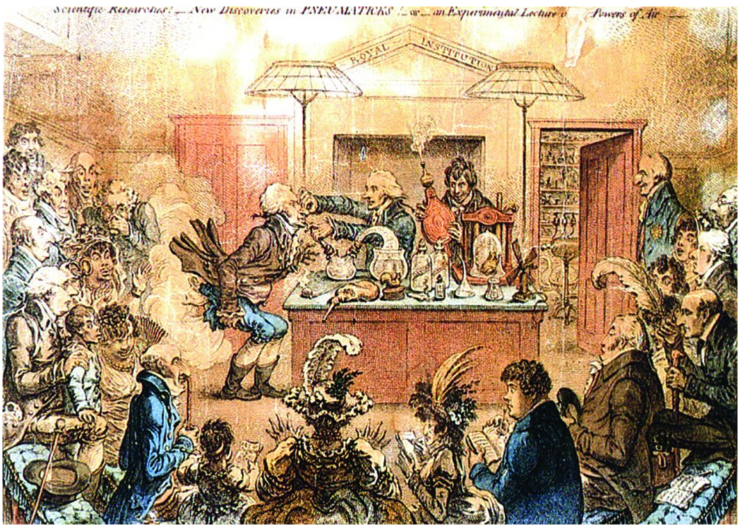

Figure 3. Hand Colored Etching by James Gillray Showing Thomas Garnett Lecturing on Laughing Gas with Humphry Davy in 1801 (Published 1802).

In Davy the Royal Institution acquired an immensely popular lecturer who attracted large audiences, including women, who were particularly enamored of him. Indeed, the readership of the famous "Conversations on Chemistry (*4*)" by Jane Marcet (1769-1858) was precisely the same as Davy's audience at the Royal Institution. It was he who firmly established the Royal Institution as a popular venue for first-rate lectures.

But, in addition, and following on from his experiences at the Medical Pneumatic Institution, Davy also introduced the idea that the Royal Institution should undertake original scientific research, something that was never envisaged by its founders. During the first decade of the 19th century, Davy developed the first coherent theory of electrochemical action in the course of which he isolated the chemical elements sodium, potassium, barium, calcium, magnesium, and strontium, and he later showed, contra the French chemists, that chlorine and iodine were indeed elements.

In 1812 the Prince Regent, later King George IV, (1762-1830) knighted Davy who three days later married Jane Apreece (1780-1855), a wealthy widow who had attended his lectures. This allowed him to retire from his professorship at the age of 34 and he delivered his final course of lectures early that year. One of Davy's auditors for those lectures was a 20-year old apprentice bookbinder with a strong interest in chemistry, Michael Faraday. Faraday, the son of a blacksmith who had moved from Westmorland to London in 1788, had a typical working-class education. The family belonged to the Sandemanians, a very small literalist sect of Christianity to which Faraday was fully committed throughout his life. The close connection between Faraday's religion and his scientific career can be summed up as his search for the laws of nature that God had written into the universe at the time of the Creation and the use of that knowledge for the betterment of humankind. To a large extent this accounts for Faraday's anti-materialistic views, for he had a strong antipathy to atoms.

During his apprenticeship Faraday had developed an overriding interest in science, particularly chemistry. He read many books on the subject, including Marcet's "Conversations on Chemistry," and attended lectures in various places, including Davy's last course at the Royal Institution which dealt with a problem then at the cutting edge of chemistry, namely the definition of acidity. Faraday took detailed notes of the lectures, and sent them to Davy asking for a job in science at the Royal Institution. After a complex set of circumstances, Faraday was appointed Chemical Assistant in the spring of 1813. In 1821 he became Superintendent of the House, in 1825 Director of the Laboratory, and in 1833 Fullerian Professor of Chemistry, a post created especially for him by the eccentric philanthropist John Fuller (1757-1834).

Following the discovery of electromagnetism in 1820 by the Danish savant Hans Christian Oersted (1777-1851), Faraday turned his attention to this subject. The following year he discovered electromagnetic rotations, the principle behind the electric motor. Ten years later, in August 1831, he discovered electromagnetic induction by, in effect, making the first transformer (Figure 4).

A few weeks later he made the first generator which produced electric current from the movement of a magnet in a coil of wire. (The originals of both these devices, together with many other pieces of Faraday's apparatus, are on permanent display in the Royal Institution). From the late 19th century onwards, the induction ring has been seen as the foundational object for electrical engineering. In 1931 enormous celebrations were held to mark the centenary of Faraday's discovery, including a two-week long exhibition at the Royal Albert Hall and a grand commemorative meeting addressed by the Prime Minister, Ramsay MacDonald (1866-1937).

Later in the 1830s Faraday studied electrochemistry, discovering his laws of electrolysis and developing with a number of classical scholars the nomenclature of electrochemistry (electrode, anode, cathode, ion, etc.), terms with which we are so familiar today. In 1836 Faraday built a twelve-foot cube covered in metal gauze (the first Faraday cage), in which he showed that electricity was a *force* rather than an imponderable fluid, as had been argued up to that time. In 1845 he demonstrated that light was affected by magnetism and that all matter possessed magnetic properties, not just iron. These experimental discoveries allowed him to formulate his field theory of electro-magnetism in which he argued that force, rather than matter, was the primary constituent of the universe. Later mathematized by his younger contemporaries William Thomson (Lord Kelvin, 1824-1907) and James Clerk Maxwell (1831-79), field theory became, and remains, one of the cornerstones of modern physics.

Figure 4. Faraday's Electromagnetic Induction Ring, First Used on 29 August 1831.

Faraday also succeeded Davy as the most attractive and engaging lecturer in the middle third of the 19th century. In the Royal Institution's Christmas Lectures for young people, established in the mid-1820s, Faraday delivered nineteen series. These included his famous "Chemical History of a Candle" which he gave in 1848-1849, 1854-1855 and again in 1860-1861. In 1861 the lectures were published (*5*) and became a highly successful book which has never been out of print in English. Subsequently the book was translated into several languages including Dutch, French, Polish, and Japanese.

Following Faraday's death in August 1867, John Tyndall was appointed to most, but not all, of his positions in the Royal Institution. Tyndall, born in Ireland, was originally a railway surveyor. He then taught mathematics at Queenwood College in Hampshire, a boys' school, before going to Marburg where he studied under Robert Bunsen (1811-99), receiving his doctorate in 1850. Tyndall took a strong interest in magnetism and thus attracted Faraday's attention. Despite their having significantly differing views on a whole range of scientific, social and ideological issues, Faraday was a strong supporter of Tyndall and in 1853 he secured Tyndall's appointment as Professor of Natural Philosophy at the Royal Institution.

Tyndall's scientific work included establishing a theory of glaciers, attacking theories of spontaneous generation and showing that the heat absorption properties of different gases varied by several orders of magnitude. From this Tyndall deduced the existence of the greenhouse effect (though he did not use that term) in the atmosphere caused by carbon dioxide. But his most notable work was in the popularization of science. He delivered a large number of lectures (including twelve series of Christmas Lectures) and wrote many books on popular scientific subjects. He coined the phrase "the scientific use of the imagination" which Arthur Conan Doyle (1859-1930) had Sherlock Holmes use in "The Hound of the Baskervilles" (1902). In his Presidential address to the Belfast meeting of the British Association for the Advancement of Science in 1874 (*6*), Tyndall made the most famous, not to say notorious, statement of his view that the world should be studied from a naturalistic viewpoint rather than a theistic one.

Research came to have an ever-increasing role within the Royal Institution as science in Britain expanded in the late nineteenth century. Following Tyndall's retirement in 1887, John William Strutt (Third Lord Rayleigh, 1842-1919), was appointed Professor of Natural Philosophy, while James Dewar (1842-1923), who had been Fullerian Professor of Chemistry since 1877, became Superintendent of the House. Rayleigh, who had moved from being Cavendish Professor of Experimental Physics at the University of Cambridge, was also a Secretary of the Royal Society and had a private laboratory at his house in Terling Place.

Dewar's appointments in 1877 and 1887 led to mounting pressure on the utilization of the available laboratory space. Although he divided his time between Cambridge (where he was Jacksonian Professor of Experimental Natural Philosophy) and the Royal Institution, his important work on cryogenics was located at the Royal Institution. This required large-scale apparatus, particularly pumps, as he sought to reach ever lower temperatures artificially, to fulfill his long term goal of liquefying hydrogen. In the course of this research in 1892 he invented the Dewar flask (now popularly known as the 'Thermos' bottle), as a container which by minimizing heat loss by conduction, convection and radiation, could hold liquid gases much longer than before.

Evolution of the Royal Institution in the 20th Century

By the end of the 19th century it was becoming increasingly clear that the practice of science would need to change considerably. In particular, scientific research needed to move from being undertaken by a single individual working in a laboratory, perhaps with an assistant, to the current situation where the head of a laboratory is generally supported by a large staff of postdoctoral assistants and research students. In part this change was driven by the expansion of scientific research throughout the world and the consequent demands for enormously large facilities compared to those of the nineteenth century.

The development of the Royal Institution reflected quite precisely these broad changes. For much of the 19th century it had possessed the best-equipped laboratory in England and one of the best in Europe. By the end of the century this was far from the case and it became clear that if the Royal Institution was to maintain its reputation as a major research laboratory it would have to change its structure. Scientific research at the Royal Institution was given a massive boost in the 1890s when the industrial chemist Ludwig Mond (1839-1909) endowed the Davy-Faraday Research Laboratory. Number 20 Albemarle Street was purchased and converted into a large modern laboratory that extended the Royal Institution's facilities beyond the two or three basement rooms that had been used hitherto. The Davy-Faraday Research Laboratory was opened by Edward, Prince of Wales (1841-1910) in 1896 with Dewar and Rayleigh as its joint first Directors. A year and a half after its opening Dewar finally achieved his goal when on 10 May 1898 he first liquefied hydrogen.

However, by the end of the Great War (the 1914-1918 conflict often referred to as World War I), with Dewar in his late 70s and refusing to retire, and with the rest of the Royal Institution's leadership of a similar age, the laboratory had become quite moribund. Dewar's death in 1923 was followed by the appointment of the Nobel laureate William Henry Bragg (1862-1942) in his place. Bragg had been educated at the University of Cambridge and had then taught mathematics and physics at the University of Adelaide in South Australia where his son, William Lawrence Bragg, was born. He had begun working on radioactivity and X-rays by 1904, and was critical of the theory of X-rays proposed by J. J. Thomson (1856-1940). So significant was Bragg's work that in 1909 he returned to England as Professor of Physics at the University of Leeds. In 1912 he and Lawrence (by now a research student at the Cavendish Laboratory, Cambridge), worked out how to determine the structure of crystals using their X-ray diffraction patterns. For this work they jointly received the Nobel Prize for Physics in 1915; Lawrence Bragg, at the age of twenty five, remains the youngest Nobel Prize winner ever.

Under Bragg the Royal Institution and the Davy-Faraday Research Laboratory both took on new vitality, restoring the place of the Royal Institution at the center of science communication and making the laboratory the most important X-ray crystallography laboratory in the world. Bragg changed the *modus operandi* of the Davy-Faraday Research Laboratory, believing in the value of directed collaborative research rather than letting individual scientists pursue their own particular interests. Thus, all of the scientists working in the laboratory from 1923 onwards collectively concentrated on understanding the structure of organic molecules. The work of Bragg and his group was particularly crucial for the development of molecular biology, which depended on understanding the atomic structure of crystals of organic materials which could be obtained only by analysis of their X-ray diffraction patterns.

The formidable team of researchers on crystallography that Bragg built up included John Desmond Bernal (1901-71), William Thomas Astbury (1898-1961), and, briefly, the only British woman ever to win (in 1964) the Nobel Prize for Chemistry, Dorothy Crowfoot Hodgkin (1910-94). Another member of Bragg's team, Kathleen Lonsdale (1903-71), the first woman to be elected (in 1945) a Fellow of the Royal Society, worked in the 1920s on the theory of space groups to help determine where possibilities of molecular symmetry might occur. A century or so after Faraday had discovered benzene at the Royal Institution, Lonsdale demonstrated, for the first time, that its structure was hexagonal and planar, and she also calculated its precise dimensions. The team structure of the Davy-Faraday Research Laboratory in the 1920s proved to be an early example of what has since become the standard pattern for undertaking scientific research.

The group at the Royal Institution formed the core of what can be identified as the British school of crystallography and later of molecular biology. Another prominent member of this school was, of course, Lawrence Bragg. He served in Flanders with the sound-ranging units during the Great War and after demobilization succeeded Ernest Rutherford (1871-1937) as Professor of Physics at the University of Manchester. In an informal agreement between father and son, they decided that William would concentrate on the structure of organic molecules while Lawrence would work on inorganic materials, particularly minerals. Lawrence remained at Manchester until the late 1930s when after a brief period directing the National Physical Laboratory he was appointed Director of the Cavendish Laboratory, again succeeding Rutherford. There he too, following the death of his father in 1942, turned his attention to organic molecules with his group, which included Max Perutz (1914-2002), John Kendrew (1917-97), Francis Crick (1916-2004), and James Watson (b.1928). In 1953 the latter two scientists, working under Bragg's direction and using the techniques he had pioneered, proposed the double helical structure for DNA – one of the key scientific discoveries of the twentieth century as it underpinned the development of molecular biology. Bragg wrote the placatory preface to Watson's somewhat biased view of the discovery in his book, "The Double Helix" (*7*).

Following the elder Bragg's death in 1942, there was a period when there were three Directors of the Davy-Faraday Research Laboratory, Henry Dale (1875-1968), Eric Rideal (1890-1974), and E. N. da C. Andrade (1887-1971). Each held the post for less than four years. Dale, as President of the Royal Society and Chairman of the War Cabinet's Scientific Advisory Committee (which William Bragg had helped to establish), was fully occupied during his period of office. Lonsdale, despite spending a month in 1943 in Holloway Prison for refusing, as a Quaker and Conscientious Objector, to register as a Civil Defence Worker, kept research going.

Following Andrade's forced resignation in mid-1952, Lawrence Bragg took over at the start of 1954. Research at the Royal Institution returned to X-ray crystallography concentrating on the structure of proteins, undertaken by Perutz and Kendrew (who held joint appointments at the Royal Institution and the University of Cambridge) for which they received the Nobel Prize for Chemistry in 1962. In the first half of the 1960s work in the laboratory turned to the structure of enzymes. This was undertaken by a group headed by David Phillips (1924-99) that included Louise Johnson (1940-2012). This project required the first computer to be installed at the Royal Institution. Paid for by the Medical Research Council, the Elliott 803 was installed in 1963, and helped Phillips and his group to make the first determination of the structure of an enzyme, lysozyme (Figure 5). It is little wonder then that Dale later wrote "It is cheering to recognise the extent to which research in 'Molecular Biology,' first at Cambridge and now at Oxford, will have been pioneered from the R.I. (*8*)"

On Bragg's retirement in 1966, George Porter was appointed Director, a position he held until 1985 when he became President of the Royal Society. Research at the Royal Institution switched to investigating high-speed chemical reactions using photo-chemical methods, with Porter and his group being able to get down to the picosecond (10^{-12} s) level. Under Porter, the heritage of the Royal Institution received considerable attention. A new archive reading room and vault was provided and a museum devoted entirely to Faraday and his work was built next to his magnetic laboratory which had survived intact from the 1850s. This museum was opened to the public in 1973 by Her Majesty, Queen Elizabeth (b.1926); this was the first time that a reigning monarch visited the Royal Institution (Figure 6).

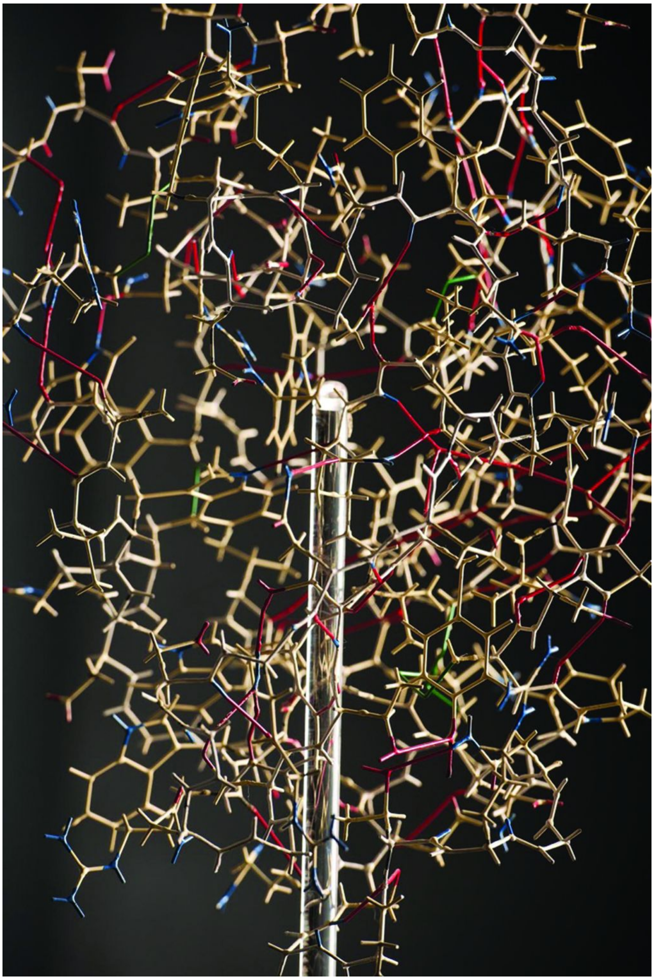

Figure 5. Model of Lysozyme, c.1965.

With the exception of Faraday's laboratory, which was unaltered, all the heritage displays at the Royal Institution were completely reinterpreted in the period 2003-2008 and formally opened by the Queen on 28 May 2008. The display now tells the story of the role that the Royal Institution has played in science for more than two centuries and how this has affected the daily lives of every individual (Figure 7). Unlike the vast majority of museums devoted to science, where the objects were created and used elsewhere, visitors to the Royal Institution can experience them in the very building where they have been always been located. Not many other sites of scientific heritage can say the same.

Figure 6. George Porter Demonstrating Picosecond Flash Photolysis to HM the Queen, 5 February 1973.

Figure 7. Current display, 2008.

The museum area in the lower ground floor, which includes Faraday's original magnetic laboratory, displays and interprets approximately 1000 objects used by Davy, Faraday, Tyndall, Dewar, the Braggs and Porter. It is open every weekday during normal office hours apart from Bank Holidays and the period from Christmas to New Year. Other areas of the building, including the lecture theatre which in its current form dates from the early 1930s, may be visited if not in use. Occasionally, the entire building is closed for special events. Visitors are advised to check the Royal Institution's web site, before making a special journey. There is no admission charge.

The Royal Institution archives (*9*) contain the papers (laboratory notebooks, lecture notes and correspondence, etc.) of all the scientists who have worked in the building as well as the Institution's administrative papers. Detailed catalogues of some of the larger collections can be found on the A2A part of the website of The National Archives (*10*). Access to the archives is strictly by appointment only which can be made via archivist@ri.ac.uk or via a downloadable form (*11*).

The Royal Institution is easily reached by tube. Exiting Green Park station (Piccadilly, Victoria and Jubilee lines) on the north side of Piccadilly, turn left (going east towards Piccadilly Circus) and then third left into Albemarle Street; you will see its impressive façade ahead on the right.

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Acknowledgments

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Chapter 6

Science in Cambridge

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Cambridge University is world-renowned with respect to a multitude of disciplines. This chapter aims to introduce the scientifically-minded reader or traveler to its rich scientific heritage as exemplified in its famous colleges and those who taught and did research in them.

Introduction

Cambridge is a city in East Anglia on the river Cam, about 65 miles northeast of London. There have been settlements in this area for more than 3,000 years. A town charter was granted in the 12th century by Henry I (1068-1135). In 1209, after some disputes with townsfolk at Oxford, a group of students fled to Cambridge and founded the University. King Henry III took an interest in the fledgling university and in 1231 intervened to protect the students and to regulate the teaching. The curriculum of the trivium (grammar, logic and rhetoric) and the quadrivium (arithmetic, geometry, music and astronomy) was followed (*1*).

There is fast (50-80 minutes) and frequent train service to Cambridge from London's King's Cross and Liverpool Street stations, and then bus service into the city center on lines Citi 1, Citi 3 and Citi 7. Alternatively, you can drive using the M11 motorway, about a 2-hour journey, and there are limited car parks near the city center.

Cambridge University is a public institution that has many academic departments and faculties. The individual colleges, however, are private bodies and do not grant degrees. These are run by Fellows, who together form the college's governing body. But in order to receive a Cambridge degree, it is necessary to belong to one of the 31 colleges. Since the university, together with its many colleges, is so complex, this chapter will treat its major developments chronologically by century beginning with the 15th. Figure 1 is a map of the university showing the locations of the sites in the order they are discussed in this chapter. In addition, the University hosts an interactive map online that is very convenient for locating virtually any building in the vicinity (*2*).

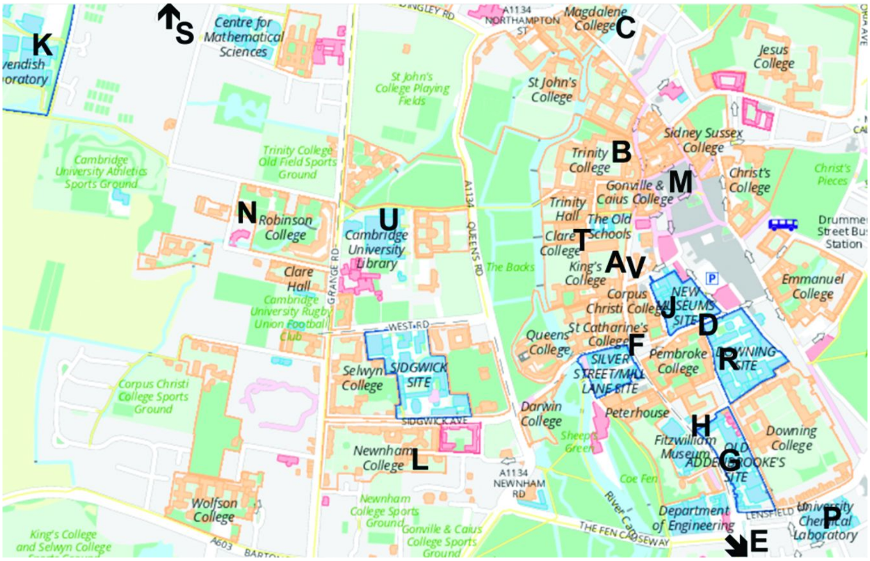

Figure 1. A. King's College; B. Trinity College; C. Magdalene College; D. Sedgwick (formerly Woodwardian) Museum; E. University Botanic Garden (off map); F. St. Catharine's College; G. Old Addenbrooke's Hospital; H. Fitzwilliam Museum; J. Free School Lane (Old Cavendish Laboratory & Whipple Museum); K. New Cavendish Laboratory; L. Newnham College; M. Gonville and Caius College; N. Needham Research Institute; P. Chemistry Department; R. Biochemistry Department; S. Churchill College (off map); T. Clare College; U. University Library; V. Eagle Pub. Map data © OpenStreetMap contributors, www.openstreetmap.org/copyright.

15th – 16th Centuries

During this period, two of Cambridge's most renowned colleges, King's and Trinity, were founded. King's College (A, Figure 1) was established in 1441 by Henry VI (1421-1471). Early in his reign, Henry VIII (1491-1547) completed, in 1515, the construction of King's College Chapel (Figure 2), which was begun in 1446. The chapel, one of the finest examples of late Perpendicular Gothic English architecture, is also one of the most beautiful buildings in England with a renowned choir of boys and men. Two very famous architectural features are its fan-vaulted ceiling and its great stained glass Netherlandish windows, although the latter not being installed until two decades later. It is well worth a visit (*3*). In 1540, the king also endowed five professorships for the university as a whole: the Regius professorships of divinity, Hebrew, Greek, physic (medicine) and civil law.

Figure 2. King's College Chapel. Cambridge University, by permission.

Another treasure at King's College is the library and its archives. Those interested in seeing these materials should contact Peter Jones (*4*), the Head Librarian, as well as the library website (*5*) and the archives website (*6*). One of the treasures of the King's College Library is the John Maynard Keynes (1883-1946) Collection of books, manuscripts and paintings. Keynes's personal library of over 1,300 books includes many editions of Hume, Newton and Locke. And while Isaac Newton (1624-1727) is best known for his mathematics and natural philosophy, much of his time was spent on alchemy and theology. Keynes donated many of Newton's alchemical manuscripts to King's College Library. Peter Jones is an expert on the Newton manuscripts.

Continuing his interest in Cambridge, Henry VIII founded Trinity College (B, Figure 1) in 1546. This renowned college (Figure 3) is associated with a vast group of scientists who are or were Fellows there. At one stage it was said that there were more Nobel Laureates from Trinity than from the whole of Germany! Four of the five past Masters of Trinity College have been Presidents of the Royal Society, namely, Alan Lloyd Hodgkin (1914-1998), Andrew Huxley (1917-2012), Michael Atiyah (b. 1929) and Martin Rees (b. 1942), the current Astronomer Royal. The fifth, Amartya Sen (b. 1933), was "merely" an Economics Nobel Laureate (now at Harvard). In the college chapel (completed 1567), there are brass plaques and sculptures commemorating the college's greatest scholars.

A small selection of the plaques includes: Lord Adrian (1890-1977) physiologist, Sir William Lawrence Bragg (1890-1971), physicist, Arthur Eddington (1882-1944) astronomer, Otto Frisch (1904-1979) physicist, G. H. Hardy (1878-1943) mathematician, Sir Gowland Hopkins (1861-1947) biochemist, Pyotr Kapitza (1895-1984) physicist, John Edensor Littlewood

(1885-1947) mathematician, Earl (Bertrand) Russell (1872-1970) mathematician and philosopher, Lord (Ernest) Rutherford (1871-1937) nuclear physicist, Martin Ryle (1918-1984) astronomer, Adam Sedgwick (1854-1913) zoologist, Sir J. J. Thomson (1854-1940) physicist, and Ludwig Wittgenstein (1889-1951) logician. There are several striking statues in the antechapel, including Francis Bacon (1561-1626) natural philosopher, Isaac Barrow (1630-1677) mathematician, William Whewell (1794-1866) historian of science and Master of Trinity (Figure 4), and most prominently the famous 1755 full-length statue by Louis-Francois Roubilliac (1702-1762) of Isaac Newton. Newton's makeshift laboratory in which he practiced alchemy for some 30 years rested against the exterior wall of the college between the lodge and the chapel.

Figure 3. Trinity College. Cambridge University, by permission.

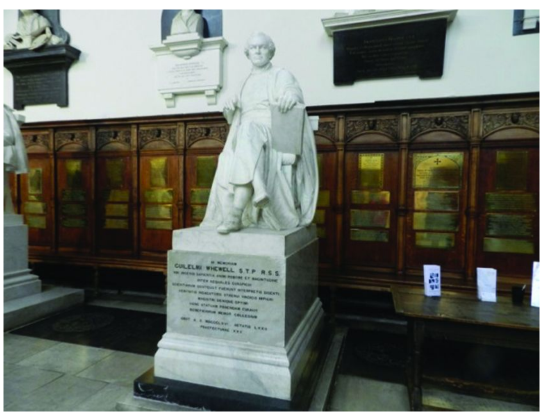

Figure 4. William Whewell, polymath and historian of science was noted for his neologisms such as "scientist," coined in 1833. It was he who suggested the terms "ion," "dielectric," "anode" and "cathode" to Michael Faraday. Photograph by Mary Virginia Orna.

Trinity College has the largest of the college libraries (Figure 5) with some 300,000 volumes. The building was designed by Sir Christopher Wren (1632-1723) and was completed in 1695. The holdings are rich in medieval manuscripts and early science books. Part of Isaac Newton's personal library is here.

Figure 5. Wren Library, Trinity College. Cambridge University, by permission.

As an aside, we should mention that each college has its own library, most of them containing extremely interesting and rare early scientific works. For example, Peterhouse has the '*Equatorie of the Planetis'* manuscript of 1393 which describes an instrument for calculating the positions of the planets. Derek de Solla Price (1922-1983) considered it to be of Chaucerian origin (*7*).

17th – 18th Centuries

The time of the flowering of science at Cambridge was during the 17th century. Professorships were established in Mathematics (Lucasian, 1663), Chemistry (1702), Astronomy and Experimental Philosophy (Plumian, 1704). This was also the era of Samuel Pepys (1633-1703), who is particularly remembered at Magdalene College (founded in 1428, C in Figure 1), where his library of 3,000 books (including the manuscript of his famous diary) resides. In a building of its own, the Pepys Library can be visited on most days in the early afternoon (*8*). Pepys was Chief Secretary to the Admiralty and was President of the Royal Society from 1684-1686. He is mentioned on the title page of the 1687 publication of Newton's *Principia* (*9*).

The Woodwardian Museum of Fossils (now the Sedgwick Museum, D in Figure 1), the university's oldest museum, was founded in 1728, having as its basis a donation of rocks and fossils by Dr. John Woodward (1665-1728), one of the founders of the science of geology. The museum presently features an exhibit of rocks and fossils collected by Charles Darwin (1809-1882) during his famous voyage aboard the *HMS Beagle*. Opening hours are M-F from 10 AM to 1 PM and 2 PM to 5 PM (Sa, 10 AM to 4 PM); the museum is free and open to the public.

Other developments taking place during this period were (1) the construction of the university's first astronomical observatory above the Trinity College gatehouse in 1704; (2) One of the most enduring traditions at Cambridge, established in 1780, is the Tripos examination in Mathematics. The Mathematical Tripos is the mathematics course taught in the Faculty of Mathematics. In the past, serious students also studied with a "coach" in order to pass the examination. The winner was designated as the "Senior Wrangler" and generally went on to a brilliant career; (3) An early version of the University Botanic Garden (E, Figure 1) was established (1760-1763) in the city center modeled on the Chelsea Physic Garden (please see Chapter 4 on London), but it later became apparent that it had to be moved to a much larger site. This was accomplished in 1831 by the then-chair of botany, John Stevens Henslow (1796-1861), a friend and mentor to Charles Darwin. Now a world-class 40-acre (16-hectare) facility, it is home to the Sainsbury Laboratory interdisciplinary research center on plant growth and development. The garden is open daily from 10 AM to 5 PM; an adult ticket is priced at £4.50 (*10*). It is located at 1 Brookside (N52.2831 E0.0451). Figure 6 is a map of the garden, and here commences a delightful walking tour.

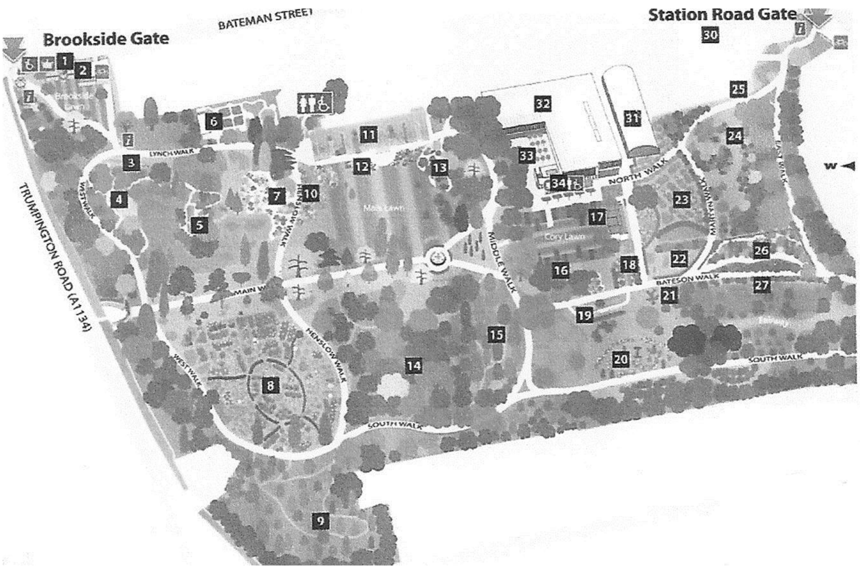

Figure 6. Plan of the Botanic Garden, Cambridge University. © OpenStreetMap contributors, www.openstreetmap.org/copyright.

The current Garden is a UNESCO world heritage listed site. Soon after entering at the Brookside Gate (1) one encounters the Stream Garden (3). One of the most interesting streamside plants is the brilliant-purple toothwort *Lathraea clandestine.* It has no chlorophyll at all and obtains its nutrients from tree roots. The Woodland Garden (4) contains a mixture of understory trees from around the world, including an *Asimina triloba*, the hardy American Pawpaw. In the middle of the lake, on a peninsula, there is a Bog Garden (5). It is centered on a beautiful Swamp Cypress (*Taxodium distichum)* and contains many bog plants such as the rare native fern, *Osmunda regalis.* On the northeastern shore of the lake is the

Limestone Rock Garden (7). This carefully planned and heroically constructed garden contains rare plants from all over the world.

One of the treasures of the Botanic Garden is the Systematic Beds (8). They were designed in 1845 by the first Curator of the Botanic Garden, Andrew Murray (b. 1810), modeled after the work of the great Swiss botanist, Augustin de Candolle (1778-1841). There are about 1600 plant species belonging to about 98 families dispersed across 157 beds. While the plantings are valuable as a scientific statement, they are also a major work of art.

The New Pinetum Garden (9) contains a diverse collection of coniferous species. The Mediterranean Beds (10) house a representative collection of species from the Mediterranean basin. The 180-m long Glasshouse Range (11) substantially extends the varieties of plants that can be displayed in Cambridge.

The walk in front of the Glasshouse (Figure 7) contains the magnificent Bee Borders (12). It is a riot of colors in summer and a great source of food for the resident bee colonies. The Terrace Garden (13) features the plants of New Zealand. The Gilbert-Carter Memorial Area (14) commemorates Humphrey Gilbert-Carter (1884-1969), the first academic Director from 1921-1950. The most notable prize in this large forest is the Cambridge Oak, *Quercus x warburgii.* The Old Pinetum Garden (15) contains some of the Garden's most majestic trees. There are many "champion trees" such as the specimen of *Pinus x holfordiana.*

Figure 7. The Glasshouse, Botanic Garden, Cambridge University. Cambridge University, by permission.

There is, in addition, a large display of British Wild Plants (16) featuring such natives as *Helianthemum.* The Cory Lodge (17) is a magnificent neo-Georgian building that houses the curatorial and horticultural teams. The Dry Garden (18) demonstrates the abundance of drought-tolerant plants that can flourish in well-watered Cambridge. England also contains ecosystems called fens which remain wet throughout the year, even when it doesn't rain locally. The Fen Display (19) illustrates the potential for beauty in such an environment. Finally, we arrive at the Rose Garden (20) which was designed by the legendary plantsman Graham Stuart

Thomas. The Rose Garden also served as the scientific laboratory of the geneticist Charles Chamberlain Hurst.

While the colleges are the center of student life, the scholarly community is centered on the university itself and its chaired Professors. Chairs in science continued to be founded throughout the 18th century: Botany (1724), Woodwardian Professor of Geology (1728), Lowndean Professor of Astronomy and Geometry (1749), and Jacksonian Professor of Natural Philosophy (1783).

One of the more interesting institutions founded in the 18th century was Addenbrooke's Hospital (1768). It was given as a bequest from Sir John Addenbrooke (1680-1719) of St. Catharine's College (F, Figure 1), where his cabinet of "curiosities" still resides. A later hospital building on Trumpington Street was designed by Matthew Digby Wyatt (1820-87) and is one of the most eye-catching buildings in Cambridge (Figure 8; G in Figure 1). It is currently used by the Judge Business School.

Figure 8. Addenbrookes's Hospital. Cambridge University, by permission.

19th Century

The 19th century witnessed the founding of the Fitzwilliam Museum (Figure 9; H, Figure 1) in 1816. The original collection included 144 pictures donated by Richard, 7th Viscount Fitzwilliam of Merrion (1745-1816). The magnificent Founder's Building of 1848 graces Trumpington Street. The collection has been described as the finest small museum in Europe. One of the treasures of interest to chemists is a George Ripley (ca. 1415-1490) alchemical scroll, of which 23 copies are extant. The museum is free and open to the public. It is open Tu-Sa 10 AM – 5 PM; Su 12 PM – 5 PM.

With the establishment of the Cavendish Laboratories in 1874, Cambridge became a great center of experimental physics. The money for the laboratory came from William Cavendish (1808-1891), 7th Duke of Devonshire and Chancellor of Cambridge University from 1861-1891. James Clerk Maxwell (1831-1879) was the first Director and was followed by Lord Rayleigh (1842-1919) and then by J. J. Thomson (1856-1940). Thomson "discovered" the electron in the Cavendish

Laboratory in 1897. There is a plaque on the wall of the former laboratory in Free School Lane (J, Figure 1) to that effect (Figure 10, right) along with the designation of the site of the Old Cavendish (Figure 10, left).

Figure 9. Fitzwilliam Museum. Licensed under Creative Commons Attribution-Share Alike 2.0 via Wikimedia Commons - Rept0n1x, http://commons.wikimedia.org/wiki/File:The_Fitzwilliam_Museum,_Cambridge,_England_-_IMG_0702.JPG.

Figure 10. Plaques on wall of Old Cavendish Laboratory, Free School Lane. Photograph by Mary Virginia Orna.

The modern site for the Cavendish Laboratories (K, Figure 1) outside of town on Madingley Road includes an outstanding museum. Instruments from its glorious history are on prominent display with good explanations. For example, original apparatus for groundbreaking research, such as F. W. Aston's (1877-1945) mass spectrometer (Figure 11) can be examined closely. Individuals are welcome to visit the museum M-F between the hours of 10 AM and 4 PM, but prior reservations are required for groups of four or more (*11*).

Although he is most famous for his theoretical work, James Clerk Maxwell took his appointment as the first Director of the Cavendish Laboratory (1874-1879) very seriously. Some of his early apparatus to measure the viscosity of gases is on display. Going from glory to glory, Lord Rayleigh followed Maxwell (1879-1884). He specialized in measuring the necessary electrical constants for the British Association Committee on Electrical Standards. His precision apparatus is also on display. With the appointment of J. J. Thomson, research into electrical discharges in gases was pursued (1884-1918). His famous Crookes tube, with which he "discovered" the electron is shown. More than electrons are moving in these tubes. Thomson also published a famous book "Rays of Positive Electricity." The apparatus used by Thomson and Francis Aston to discover atomic isotopes is one of the best exhibits. Charged particle physics is represented by C. T. R. Wilson (1869-1959) and his "cloud chamber." The rectifier tube from the original 1930 Cockcroft-Walton particle accelerator machine is shown (*12*). Lord (Ernest) Rutherford directed the Cavendish from 1919-1937. His alpha-particle apparatus and his "disintegration chamber" are displayed. Electron microscopy was developed at the Cavendish and an early version is on display. Ultralow temperature physics was associated with Peter (Pyotr) Kapitza, the Director of the Mond Laboratory and one of his helium liquifiers is shown. In 1938 W. Lawrence Bragg returned to Cambridge as Director and one of the elder Bragg's x-ray spectrometers is presented. The original model of DNA used by Watson and Crick is familiar to many people (see below for the story). The Cavendish Museum collection is priceless and truly awesome.

Figure 11. F. W. Aston's Mass Spectrometer. Photograph by Mary Virginia Orna.

20th Century

Another remarkable current resource is the Whipple Museum for the History of Science (J, Figure 1) on Free School Lane in the Old Physical Chemistry Building (Figure 12). Both books and artifacts are on display. And the museum has working historians of science available for consultation. Contact Liba Taub (*13*) before planning a visit. The museum is free and open to the public. It is open M-F from 12:30 to 4:30 PM.

Robert Stewart Whipple (1871-1953), former head of the Cambridge Scientific Instrument Company, was an avid book, artifact and scientific instrument collector who donated more than 1,400 books that now form the nucleus of a great collection of rare books. A special edition of Gilbert's *De Magnete* issued by Sylvanus Thompson is a nice example (*14*).

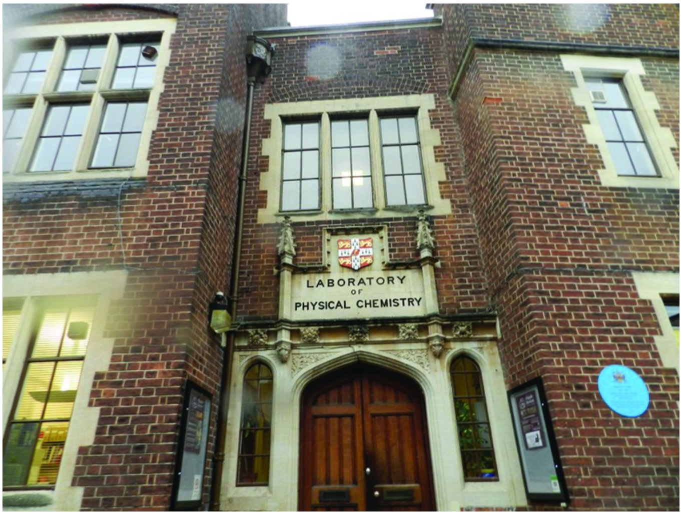

Figure 12. The Whipple Museum. Photograph by Mary Virginia Orna.

One of the treasures on display in the artifact museum is a fume hood (Figure 13) rescued from the laboratory in the grounds of the women's Newnham College (L, Figure 1), founded in 1871. In the first years of its existence, women were not allowed to undertake practical chemistry classes with men. The Newnham girls were taught chemistry in their college by the formidable Austrian, Ida Freund (1863-1914), a noted historian of chemistry.

Most colleges have connections with prominent scientific figures. Gonville and Caius College (M, Figure 1) was where William Harvey (1578-1657) was a student, though the work which led to his understanding of the circulation of the blood was carried out at Padua in Italy. A recent Master was Joseph Needham (1900-1995), the great biochemist and historian of Chinese science, technology and medicine. Up to his death, 16 volumes of *Science and Civilization in China* had been published, and the work continues in the Needham Research Institute

(N) which, since 1991, has been situated at 8 Sylvester Road behind Robinson College. Presently, eleven volumes on chemistry and chemical technology have been published.

The Chemistry Department has been situated in Lensfield Road (P, Figure 1) since the 1950s and the Biochemistry Department can be found in Tennis Court Road (R, Figure 1). Twenty-one chemists affiliated in some way or other to Cambridge have won Nobel Prizes. For example, the biochemist, Frederick Sanger (1918-2013), won two, in 1958 and 1980.

Figure 13. Fume Hood from Newnham College. Photograph by Mary Virginia Orna.

A relatively new institution is Churchill College (S, Figure 1), established to perpetuate the contribution made to the country by Sir Winston Churchill (1874-1965). Its first Master was Sir John Cockcroft (1897-1967), the physicist who, with Ernest Walton (1903-1995, Trinity College), shared the Nobel Prize for splitting the atomic nucleus. Other alumni of Churchill include C. P. Snow (1905-1980) a chemist and novelist who introduced the concept of 'The Two Cultures' in the Rede Lecture of 1959. Francis Crick (1916-2004) was an honorary fellow who together with James Watson (b. 1928, Clare College; T in Figure 1) proposed the double helix structure of DNA in 1953. Crick, a humanist, resigned his fellowship over the construction of a chapel on the college grounds.

One of the major historians of Chemistry of the 20th century was James Riddick Partington (1886-1965), a physical chemist whose multi-volume *A History of Chemistry,* published between 1961 and 1970, are a landmark in the field. He wrote this as a retirement project after he moved from Queen Mary College, London to Cambridge in 1951. Until he left for Manchester in 1964 he lived very modestly at 211 Mill Road (N52.1973 E0.1470), Cambridge.

Cambridge University Library

One of the great university facilities is the main library (U, Figure 1). It was founded in the 15th Century. It is one of the five "Copyright Libraries" noted in the Act of Queen Anne in 1709. It can claim a copy of any book that receives a copyright in the UK or Ireland. The library has been the beneficiary of many royal gifts over its history. Its current collection is priceless and contains over 8 million items. Many incunabula are included in the rare book collection. Access is restricted but there is usually an exhibition available for public view.

Figure 14. Cambridge University Library. Cambridge University, by permission.

Eagle Public House

One of the oldest remaining pubs in Cambridge (founded 1667) is the Eagle (V, Figure 1). While it served many a Fellow, it became famous in the 20th century as the hangout of Cavendish Laboratory scientists. It is located on Bene't Street in a building owned by Corpus Christi College.

The 'Airman's' bar (so-called because it was frequented by British and American air force personnel during World War II) contains a brass plaque commemorating the announcement by Francis Crick on 28 February 1953 that he and James Watson had "discovered the secret of life." (Figure 15) They still serve the Eagle's DNA Ale to keep the memory alive. A blue plaque outside the pub also notes the event.

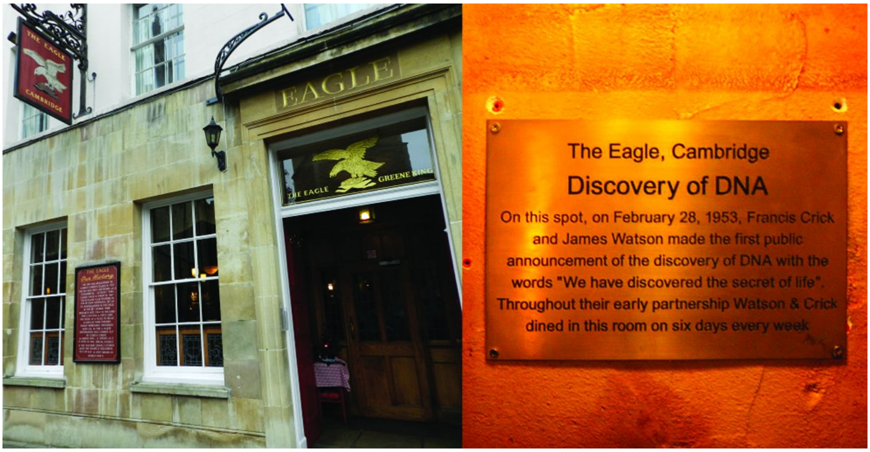

Figure 15. Entrance to the Eagle Public House (left); Commemorative plaque in the 'Airman's Bar' (right). Photograph by Mary Virginia Orna.

Conclusion

Science is not a disembodied collection of mere "facts." Actual science is carried out in real places by real people. One of those places is Cambridge. While the history of science in Cambridge reaches back to the days of Barrow and Newton, the "Great Age" of science on the Cam is now. The sheer density of scholarly books, papers and artifacts in Cambridge is stunning. It is easy to transport oneself into the past and imagine scientific life at Trinity College. But, Nobel Prizes are still being won for work done at Cambridge. With both the actual entities of the past and the current professional staff, exploring the history of science in Cambridge is a bracing experience. In order to fully realize the potential of Cambridge as a place for a scientific study tour, I would encourage planning well in advance to meet with the current scholars as part of the visit. Not only can they give good advice about where to look in Cambridge, they can help put the history in perspective.

Suggested Further Readings

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Acknowledgments

This chapter has benefitted substantially from Dr. Robert G. W. Anderson, a resident of Cambridge and Fellow of Clare Hall. I also wish to thank Mary Virginia Orna for providing photographs taken on our November 2013 visit to Cambridge. The pilgrimage to Cambridge was arranged by Robert Anderson.

Notes and References

1. See (a) Lauh, M. J., Sr. *The Trivium: The Liberal Arts of Grammar, Logic & Rhetoric*; Paul Dry Books: Philadelphia, 2002. (b) Robinson, M. *Trivium 21c: Preparing Young People for the Future with Lessons from the Past*; Independent Thinking Press: London, 2013.
2. University of Cambridge Map. https://map.cam.ac.uk/.
3. King's College. Admission and Opening Timeshttp://www.kings.cam.ac.uk/visit/admission.html. The chapel is open from approximately 9:30 AM to 3:30 PM, but times vary depending on the academic year calendar. An adult ticket is £7.50.
4. E-mail for Peter Jones, King's College: peter.jones@kings.cam.ac.uk.
5. King's College. Library. http://www.kings.cam.ac.uk/library/index.html.
6. King's College. Archive Centre. http://www.kings.cam.ac.uk/archive-centre/index.html.
7. Cambridge Digital Library. Equatorie of the Planetis. http://cudl.lib.cam.ac.uk/view/MS-PETERHOUSE-00075-00001/1.
8. Magdalene College. Opening Hours. http://www.magd.cam.ac.uk/opening-hours/.
9. Philosophiæ Naturalis Principia Mathematica. Wikipedia. http://en.wikipedia.org/wiki/Philosophi%C3%A6_Naturalis_Principia_Mathematica.
10. Cambridge University. Botanic Garden. www.botanic.cam.ac.uk.
11. Visit the Cavendish Museum. http://www-outreach.phy.cam.ac.uk/cav_museum/.
12. The generator developed by John Douglas Cockcroft (1897-1967) and Ernest T. S. Walton (1903-1995) won them the 1951 Nobel Prize in Physics for

“transmutation of atomic nuclei by artificially accelerated atomic particles.” Theirs was the first particle accelerator, an invention that transformed modern physics and the periodic table.

13. E-mail for Liba Taub, Whipple Museum for the History of Science: lct1001@cam.ac.uk
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Chapter 7

Paris: A Scientific "Theme Park"

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There is more science concentrated in one small area of Paris than perhaps in all of the rest of France. This "tour" will uncover some of the most remarkable discoveries, including the discoveries of ten elements, radioactivity, stereochemistry, and much, much more.

Introduction

When visiting Paris as a casual tourist, the first things that come to mind are the world-class museums like the Louvre, the Musée D'Orsay and the Centre Pompidou. Much less on people's minds are the equally world-class scientific museums, some of which are household words to chemists and physicists, and some that should be. There are also other "scientific sites" in Paris that deserve attention, and this essay will bring some of these to the fore. Some of them involve the places where elements were discovered: no less than ten were found within a few kilometers of one another, mostly in the Latin Quarter around the Sorbonne. Here is a reference list:

In Science History: A Traveler's Guide; Orna;

Table I. Chemical Elements Discovered in Paris (*1*)

Element	*Atomic No.*	*Date Discovered*	*Discoverer(s)*	*Location**
Beryllium (Be)	4	1798	L. N. Vauquelin (1763-1829)	71 rue de l'Université (7th)
Fluorine (F)	9	1886	H. Moissan (1852-1907)	R. Michelet (5th)
Chromium (Cr)	24	1797-1798	L. N. Vauquelin	71 rue de l'Université (7th)
Iodine (I)	53	1811	B. Courtois (1777-1838)	9 (31) rue St. Ambroise (11th)
Europium (Eu)	63	1896	E.-A. Demarçay (1852-1903)	2 Blvd. Berthier (17th)
Lutetium (Lu)	71	1907	G. Urbain (1872-1938)	Sorbonne (5th)
Polonium (Po)	84	1898	P. & M. Curie	42 rue Lhomond (5th)
Francium (Fr)	87	1939	M. Perey (1909-1975)	1, rue Pierre et Marie Curie (5th)
Radium (Ra)	88	1898	P. & M. Curie	42 rue Lhomond (5th)
Actinium (Ac)	89	1899	A.-L. Debierne (1874-1949)	Sorbonne (5th)

* The numbers in the location column refer to the Paris arrondissements.

The Curies

The first thing that would come to a chemist's or physicist's mind regarding the science once done in Paris is the incredible, and still to this day incredible, accomplishments of the team Curie: Marie Skłodowska Curie (1867-1934), Pierre Curie (1859-1906), Irène Joliot-Curie (1897-1956), and Frédéric Joliot-Curie (1900-1958), plus the many stars that shone around them in their laboratory over the years: André Debierne (1874-1949), Ellen Gleditsch (1879-1968), and Marguerite Perey (1909-1975), to name a few. There are many websites and even more books (*2–4*) and articles (*5*) that document their accomplishments. The American Institute of Physics page (*6*) provides not only biographical information, but also material on the Curie Institute today as well as the Curie Museum, the latter in French. Not only that, they also provide a link to a "Marie Curie Walking Tour of Paris."

Figure 1 provides a map of the area with the key sites marked. Each of them will be discussed in the following paragraphs.

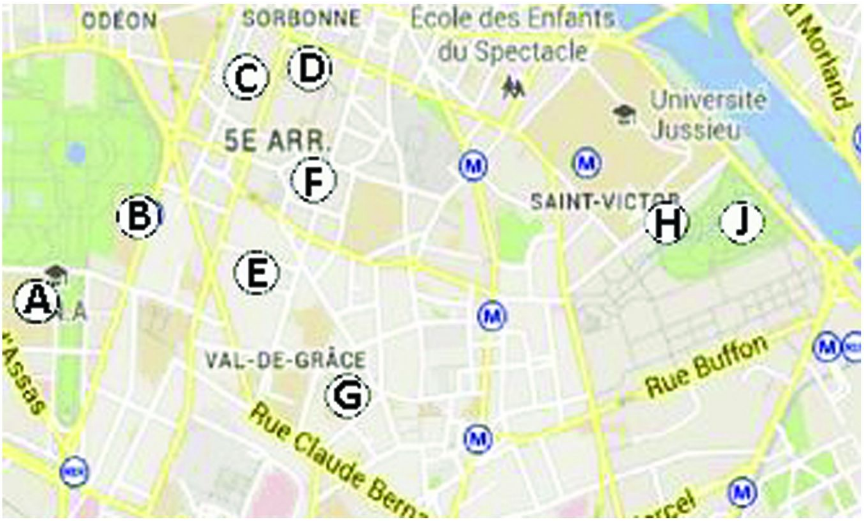

Figure 1. A map of the 5th arrondissement with part of the 6th arrondissement on the left. A. Faculté de Pharmacie, Moissan Museum, Vauquelin Statue at 4 rue de l'Observatoire; B. Musée de Minéralogie housed in the Ecole des Mines, 60 Blvd. St. Michel; C. Some buildings of the Sorbonne; D. Collège de France; E. Curie Museum, 1 rue Pierre-et-Marie-Curie; F. Panthéon; G. Ecole Supérieure de Physique et de Chimie Industrielles de la Ville de Paris (ESPCI), 10 rue Vauquelin; H. rue Cuvier and Jussieu Campus, Sorbonne; J. Jardin des Plantes - Map Data @2014 Cybercity, Google.

The Curie Museum

The Curie Museum occupies the ground floor of the *Institut du Radium*, 1 rue Pierre-et-Marie-Curie, 75005 Paris (E in Figure 1; nearest Métro stop: Luxembourg) (*7*) just one block from where the Rue Gay-Lussac and the Rue Saint-Jacques intersect. It is open Tuesday through Saturday, but only in the afternoon from 1:00 PM to 5:00 PM. Here you can visit Marie Curie's office (Figure 2), looking today much as it did back in the 1930s when she occupied it, although her laboratory notebooks are only available at the *Bibliothèque nationale* and, since they are highly radioactive, you must sign a release to examine them.

At the museum, there are also some permanent displays and some temporary exhibits and programs, often on designated Saturdays of the month; it is wise to check the website for the time when you expect to be in Paris. None of the famous radium work was done here, but you can visit the original site while on the walking tour described below.

Figure 2. Marie Curie's Office at the Institut du Radium. Photograph: Mary Virginia Orna.

The Marie Curie Walking Tour of Paris

The site (*8*) provides an annotated map of the Latin Quarter area (5th-6th arrondissements) where Marie lived prior to and during her marriage, where she worked, and where she was finally buried. It begins at the Port Royal Métro stop and ends at the Pont Neuf (despite its name, the oldest bridge in Paris), the site of Pierre Curie's fatal accident in 1906. One of the more interesting stops on the tour is number 5, the ESPCI (Municipal School of Industrial Physics and Chemistry) where Pierre Curie was a faculty member. The original radium/polonium work – the first detection and naming of these elements - was done at this site. The main entrance, which used to be at 42 rue Lhomond, at the present intersection of rue Lhomond and rue Pierre Brosselette, can no longer be identified by any landmarks. The entrance to the new building (Figure 3; G in Figure 1), renovated and dedicated in 2007 to the memory of physics Nobel laureate Pierre-Gilles de Gennes (1932-2007) is at 10 rue Vauquelin. The plaque to the left of the vehicle entrance gives a brief history of the school and includes a quotation by Pierre Curie, who worked here for over 20 years before moving on to the Sorbonne (C in Figure 1) and the *Collège de France* (D in Figure 1), witnessing to the supportive research atmosphere in which he found himself. A plaque to the right of the door (Figure 4) announces the discovery of radium. Unfortunately, you have to get special permission to get into the building which contains a nice collection of the original equipment used by the Curies (*9*).

As you walk through the vehicle entrance, it is possible to catch a glimpse of the parking lot where once stood the famous "shed" in which Marie Curie sifted through tons of pitchblende in her search for the elusive radium, but the guardians of the school may not allow you to advance any farther.

Figure 3. ESPCI (Ecole Supérieure de Physique et de Chimie Industrielles de la Ville de Paris). Photograph by Mary Virginia Orna.

Figure 4. This plaque at rue Vauquelin 10 designates the location of the discovery of radium. Gustave Bémont (1857-1937) is the often overlooked chemist of the group. Photograph by Mary Virginia Orna.

Over on the east side of the 5th arrondissement is the huge Jussieu campus (Métro: Jussieu; H in Figure 1) of the *Université Pierre et Marie Curie* (UPMC) at 4 Place Jussieu. Part of the Sorbonne complex, the campus is home to the *Institut de Minéralogie et de Physique des Milieux Condensés* which, in turn, is home to the Jussieu Mineral Collection, one of the oldest museums of mineralogy in the world (*10*). Founded in the early 1800s, the collection contains over 16,000 specimens (of which only 10% are on exhibition) and is both a museum and a research center. It is open daily, except Tuesdays, from 1.00 PM to 6:00 PM.

Down the block from the modern campus, in rue Cuvier (Métro: Place Monge), is the old Faculty of Sciences building of the University of Paris, where Pierre, and later Marie Curie, taught. The original building has changed a great deal since 1900, but is still recognizable (Figure 5). Behind this building is a small "shed" (Figure 6) which resembles the original "shed" in Rue Lhomond; it is another site, also highly radioactive, where Marie Curie carried on her research after her move to the Faculty of Sciences. It is only accessible through the main entrance of the complex. Today it remains unused for obvious reasons. Directly across rue Cuvier from the Faculty of Sciences building is an entrance to the *Jardin des Plantes* (H in Figure 1) which affords access to Cuvier House, named after former resident Jean Léopold Nicolas Frédéric Cuvier, aka Georges Cuvier (1769-1832). Later in the 19th century, precisely in 1896, it was the scene of the discovery of radioactivity (Figure 7) by Henri Becquerel (1852-1908) – for which he shared the Nobel Prize in physics with the Curies.

Becquerel's great insight was that the radiation emanating from uranium salts came from the substance itself and not from any type of excitation producing phosphorescence or fluorescence, which were well-known at the time. The young Marie Skłodowska seized upon his discovery and set about trying to determine the nature of this mysterious phenomenon. That she would succeed beyond all expectations is now a matter of history that marks this very special section of Paris.

Figure 5. Faculty of Sciences building, University of Paris. Left: the building as it appeared in 1900; right: the building as it appeared in 2013; it is now annexed to a larger complex called the Langevin Institute. Photomontage by Mary Virginia Orna.

Figure 6. Second "shed" where the Curies worked beginning in 1903, five years after the discovery of radium. Photograph by Mary Virginia Orna.

Figure 7. Front side of Cuvier House, which faces inward to the Jardin des Plantes and away from rue Cuvier. Photograph by Mary Virginia Orna.

The *Jardin des Plantes* (J in Figure 1) is a special place in and of itself. Once under the directorship of the chemist, Michel Eugène Chevreul (1786-1889), which is commemorated by the statue that stands in the garden (Figure 8), it became a scientific research center that rivaled the University of Paris. Today its emphasis is on natural history and one can spend a very pleasant afternoon exploring its many treasures. One such is the *Grande Galérie d'Evolution* (Great Hall of Evolution) shown in Figure 9, a natural outcome of the pioneer evolutionists who worked at the Jardin – Jean-Baptiste Lamarck (1744-1829) and Etienne Geoffroy Saint-Hilaire (1772-1844). And this is a must-see if you brought the children along.

A fitting end to the walking tour would be a visit to the *Panthéon* (F in Figure 1) to pay homage to the Curies as they rest in peace – their tomb is always decorated with fresh flowers.

Figure 8. Former Director of the Jandin des Plantes, Michel Eugène Chevreul. Photograph by Mary Virginia Orna.

Figure 9. Grande Galérie d'Evolution. Photograph by Mary Virginia Orna.

In the Curie "Neighborhood"

Moving into the 6th arrondissement, but not at all far from the Curie landmarks just across the Boulevard Saint Michel, we come to a couple of little treasures, one of which may require some effort to unpack. The little known Musée Moissan, dedicated to the 1906 Nobel laureate in chemistry (Ferdinand Frederick) Henri Moissan (1852-1907), is maintained by the *Faculté de Pharmacie of the Université René Descartes*. Located at 4 rue de l'Observatoire (A in Figure 1), unfortunately it does not have regular visiting hours; an appointment is required (+ 33 (0)8 99 23 60 18; no email address). Failing that, you can wander around the building and pay homage to Moissan by seeing the lecture room named in his honor, and reminiscing on his success in isolating elemental fluorine without killing himself (*11*). You can also wander outside and sit at the feet of Louis-Nicolas Vauquelin (1763-1829), the discoverer of chromium and beryllium (Figure 10).

Figure 10. Statue of Louis Nicolas Vauquelin outside the Faculty of Pharmacy building, 4 rue de l'Observatoire. Photograph by Mary Virginia Orna.

Snuggled into the east side of the Luxembourg Gardens at Boulevard Saint Michel 60 is the School of Mines (B in Figure 1; nearest Métro stop: Luxembourg). Although the School of Mines was established in 1783 in order to educate future mining engineers, it ceased operating in 1791 due to lack of funding. In 1794, a new school, consisting of a laboratory, a library, and a mineral collection, was established, and an 1816 decree restored its educational mission, at the service of industry and society. Today the school investigates, develops and teaches a variety of useful concepts for engineers, including the economic and social sciences. Its library grew due to confiscations during the Revolutionary period and it now includes a comprehensive collection on the art of mining and metallurgy, and some precious manuscripts dating back to the early 16th century.

The Mineralogy Museum was officially established in 1794, building on earlier collections. It was decreed that the museum should contain every known mineral specimen arranged according to provenance. This is still the case today. In 1795, the Abbé René-Just Haüy (1743-1822), newly released from a Revolutionary prison, was named the first curator (Figure 11). He published his five-volume treatise on mineralogy in 1801 and became known as the father of modern mineralogy and crystallography. It was actually Haüy who suggested to Vauquelin that he investigate emeralds and beryl, since they had the same crystal structure. Indeed, Vauquelin found they were identical -- thereby discovering beryllium (*12*). The collection, one of the greatest in the world, today is housed in 2,000 square meters of 250 interconnected glass cases and 2,400 drawers of solid oak, a masterpiece of 19th century cabinet-making. The minerals themselves are masterpieces of nature in use today in a variety of ways. For example, NASA requested minerals to use as standards in its next exploration of Mars, and the Necker Hospital of Paris requested some specimens of calcium oxalate to make a clinical comparison with human kidney stones. Figure 12 shows the grand staircase by which one accesses the collection.

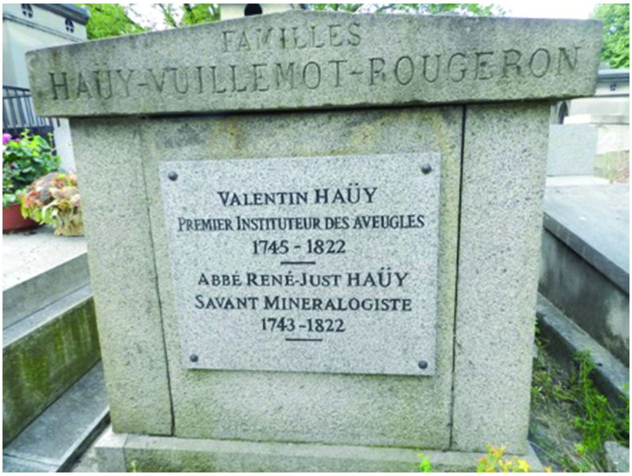

Figure 11. Tomb of Abbé René-Just Haüy. Père Lachaise Cemetery, Paris, Division 60. Photograph by Mary Virginia Orna.

The museum is open Tuesdays through Fridays from 1:30 to 6:00 PM and on Saturdays from 10:00 AM to 12:30 PM and from 2:00 to 5:00 PM. Although photographs in the collection are not permitted, some spectacular specimens can be seen on the museum's website (*13*).

For geology buffs, the 5th arrondissement is also an area of enormous interest. Armed with a copy of *Promenade géologique à Paris 5e*, a detailed, illustrated walking tour guidebook (*14*), you can spend a delightful day examining the public buildings, churches, bridges, sidewalks, altar marbles, and statuary that abound in the area. A similar booklet (*15*) is available for the 11th arrondissement. Both booklets can be purchased at the Museum of Mineralogy.

Figure 12. The Grand Staircase, entrance to the School of Mines Museum of Mineralogy. Murals depict some of the geological wonders of nature like Mont-Blanc and Fingal's Cave. Photograph by Mary Virginia Orna.

The *Conservatoire national des Arts et Métiers*

Somewhat off the beaten track up in the third arrondissement (Métro: Arts-et-Métiers) is my favorite museum at 60 rue Réaumur. It has a venerable history, having been founded in 1794 by the Abbé Gregoire precisely to showcase new and useful inventions. Originally housed in the abandoned priory of Saint-Martin-des-Champs, and renovated in 2000, it has become the museum par excellence of technological innovation. It presently displays over 3,000 inventions (only about 4 percent of the museum's holdings) in seven different collections: scientific instruments, materials, energy, mechanics, construction, communication, and transportation.

One of the museum's chemical highlights is a simulated laboratory of Antoine Laurent Lavoisier (1743-1794; Figure 13) and a display of his incredible balances.

The principal gravimetric tool then, as now, was the analytical balance or one of its more modern derivatives. In 1785, Lavoisier stressed that his published results were based on repeated weighing and measuring experiments which were the only criteria for admitting anything in physics and chemistry. Because he was carrying out experiments that required heretofore never achieved precision and accuracy, it is well-known that he spent a fair amount of his fortune on the best scientific apparatus that money could buy, often designing the instrument himself and then having it purpose-built by a specialist such as the foremost scientific instrument maker of the era, Nicolas Fortin. His famous gasometers, constructed by P. Mégnié between 1785 and 1787, were capable of measuring simultaneously the weight and volume of a gas with such high precision that no one else was able to verify his experimental results. By weighing masses of hydrogen and oxygen both before and after they were reacted to form water, he was able to experimentally demonstrate the law of conservation of mass.

This so-called analytical approach (*16*) to the elements, that of concentrating on concrete laboratory substances as opposed to metaphysical speculation about the ultimate components of substances, has been presented as central to the chemical revolution. It is awesome to realize that in visiting this museum display, one is in the presence of the very instruments that helped bring about this revolution (*17*).

Figure 13. A simulated laboratory of A. L. Lavoisier; note the two gasometers for weighing gases using the precision balances built for that purpose. Photograph by Mary Virginia Orna.

Hundreds of other scientifically interesting artifacts draw your attention in this museum. For example, illustrated in Figure 14 are examples of Blaise Pascal's (1623-1662) calculating machine, invented in 1642 to facilitate his father's work as a tax assessor, and in Figure 15 the cyclotron from the *Collège de France*. This instrument, one of the first of its kind in Europe (1937), was used by Irène and Frédéric Joliot-Curie in their work on nuclear transmutation.

In 1671, Father Chérubin d'Orléans (1613-1697) wrote "*La dioptrique oculaire*," a landmark in optical history that included illustrations and details on the construction of binocular telescopes. The *Arts et Métiers* museum actually possesses a 1681 set of binoculars constructed by Father Chérubin according to his written principles. Among the museum's other optical holdings is a set of camerae obscurae for daguerreotyping constructed by Charles Chevalier (1804-1859) in 1840-1841. At around the same time, he constructed the first folding camera and the first whole-plate box camera.

Figure 14. Examples of Blaise Pascal's 1642 calculating machine. Its principal innovation seems very basic to modern eyes: it adds or subtracts, carrying over automatically. Photograph by Mary Virginia Orna.

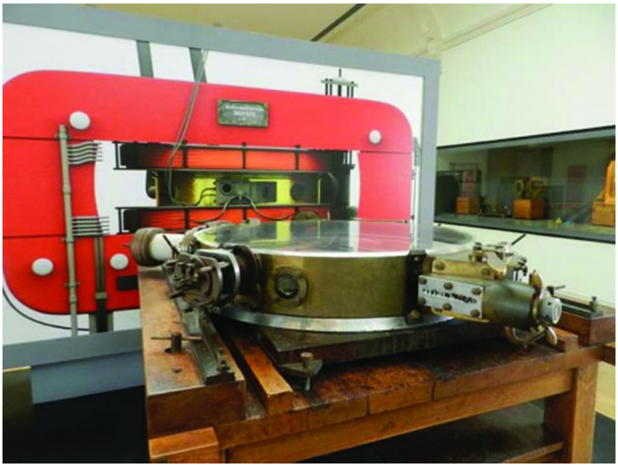

Figure 15. The Cyclotron used by Irène and Frédéric Joliot-Curie at the Collège de France (1937). The instrument and its accompanying power supply (shown in simple outline in this display) weighed over 25 tons and had an output of 7 MeV, which was remarkable for that era. Photograph by Mary Virginia Orna.

The original building of the museum, the church of Saint-Martin-des-Champs, is a wonderland in and of itself. In addition to an original version of Foucault's pendulum, up to which one can get very close and personal as illustrated in Figure 16, in contrast to the gigantic model in the *Panthéon*, there are other attractions for the kids, or for the kid within us. Frédéric-Auguste Bartholdi's (1834-1904) original 1878 plaster model of the Statue of Liberty commands the field at almost 9.5 feet in height. And some of the first fantastic "flying machines" designed by French engineers seem to swoop down out of the ceiling like fire-breathing dragons: Clément Ader's (1841-1925) Avion III and Louis Blériot's (1872-1936) eponymous trial XI.

If you can tear yourself away from this marvelous museum, a short walk of four blocks down rue Beaubourg brings you to rue Montmorency. Turn right and midway down the block on your left, you will see a restaurant at no. 51 that bills itself as the Auberge Nicolas Flamel "since 1407." This is historically the oldest stone house in Paris. It was also the home of Nicolas Flamel (ca. 1330-1418 or 1992) and his wife Pernelle (or Perenelle). Supposedly an alchemist who discovered the elixir of life that allowed him to make his appearance as a friend of Dumbledore in the Harry Potter novels, Flamel obtained this reputation only posthumously, being a manuscript dealer in real life. Continuing to walk into the 4th arrondissement brings you to rue Nicolas Flamel which runs parallel to the River Seine between the Pont Notre Dame and the Pont au Change (Figure 17). Appropriately enough, it intersects with rue Pernelle (named after Flamel's wife).

Figure 16. Foucault's Pendulum in the Church of Saint-Martin-des-Champs, Arts et Métiers Museum. Photograph by Mary Virginia Orna.

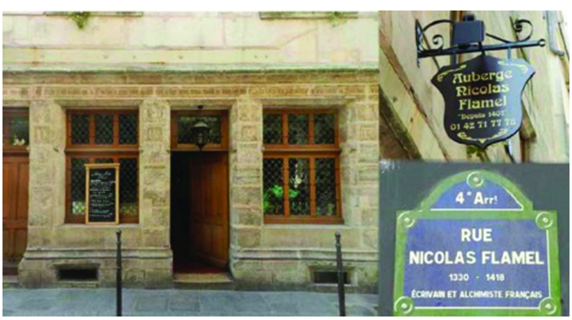

Figure 17. Auberge and Rue Nicolas Flamel. Photographs by Mary Virginia Orna.

The Pasteur Museum

I once heard someone ask the question "What is the most famous name in science?" and the answer shot back immediately was "Einstein." I begged to differ since the name "Pasteur" is printed on every milk carton of commercially sold milk, at least in the United States. It also graces many other products that have undergone the pasteurization process. The museum (Métro: Pasteur; 15th arrondissement) dedicated to this remarkable man, Louis Pasteur (1822-1895), is equally remarkable. Located at 25, rue du Dr Roux, about one block from the Métro stop, it is an historic monument divided into three distinct sections.

Founded in 1935, the museum preserves Pasteur's memory in the large apartment made available to him at the institute bearing his name, where he spent the last seven years of his life. The rooms are preserved as they were with all of the furniture, household items, art, and photographs that surrounded the family, giving one a feeling for their private life.

The funeral chapel, in a crypt below the museum building, contains Pasteur's granite tomb. The crypt itself is sumptuously decorated in the Romanesque-Byzantine style by multi-colored mosaics that depict his many discoveries.

Of greatest interest to scientists is the room of scientific mementos where over 1,000 objects pertaining to Pasteur's work and discoveries are collected and displayed. There are crystals, flasks, and vials containing original materials, microscopes, polarimeters, autoclaves, and much more that allow one to appreciate Pasteur's wide-ranging and exceptional work in crystallography, fermentation, silkworm diseases, animal vaccines, and rabies prophylaxis.

One item on display in this room might send shivers up and down the spine of a chemist, especially an organic chemist: Pasteur's original hand-carved models of the D- and L-forms of tartaric acid crystals (Figure 18). These seemingly simple models, representative of the resolution of an optically active compound, radically changed our view of the world and opened up whole new fields of research.

A little background. The Swedish chemist, Carl W. Scheele (1742-1786), first isolated tartaric acid in 1769 from the solid residue remaining from fermenting grapes. Fifty years later, an acid with similar composition but different properties, was isolated as a byproduct of the large-scale production of tartaric acid: it was called racemic acid (from the Latin word, *racemus*, meaning a "bunch of grapes"). The astounding observation regarding these two acids, both exhibiting virtually identical crystalline forms, was the behavior of their salts in solution: tartrate rotated the plane of polarized light, while racemate did not. Pasteur, examining the tartrate salts with a different purpose in mind, noticed a crucial difference that other researchers had overlooked: while the crystals of tartrate and racemate (Pasteur called it paratartrate) were asymmetric and hemihedral, those of the latter salt consisted of two types of asymmetric crystals non-superimposable on one another much as a left hand cannot be superimposed on a right hand (*18*). He immediately perceived this analogy, realizing that the racemate salt consisted of a mixture of "right-handed" and "left-handed" crystals (later dubbed "enantiomers"). Painstakingly separating by hand these two types of crystals from what came to be called a racemic mixture, Pasteur demonstrated that a solution of the "right-handed" crystals rotated polarized light to the right, while an equal concentration of a solution of "left-handed" crystals exhibited equal rotation to the left. Furthermore, he realized the impossibility of creating asymmetric compounds from symmetric starting materials, thus concluding that asymmetric molecules were essential components of living systems, and that laboratory synthesis of asymmetric compounds would lead only to racemic mixtures, that is, mixtures containing equal quantities of a pair of enantiomers. "Pasteur was the first to show unequivocally a distinct relationship…between crystalline form, optical activity, and asymmetry at the molecular level. [He] did not simplify or make improvements to the techniques in measuring optical activity, but demonstrated that optical activity could be a useful property for chemists to consider, thereby justifying its greater application (*19*)."

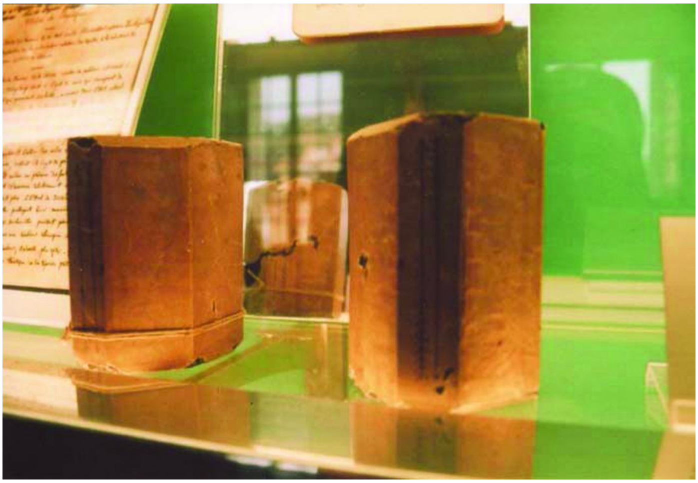

Figure 18. The D- and L-forms of tartaric acid, made of wood by Pasteur. The mirror behind the models allows you to look at the D-form and see its reflection as L-, and vice-versa. Photograph courtesy of Roger Rea.

Pasteur's concentration and thorough attention to detail bore fruit in many other areas that eventually gave rise to entire disciplines. His work on fermentation put to rout the long-held erroneous concept of spontaneous generation and opened up the field of microbiology. One of his most spectacular discoveries was how inoculation against rabies worked and that it worked in human beings. In 1885, his courageous successful treatment of a boy, Joseph Meister, with his newly developed rabies vaccine made him a national hero overnight (Figure 19) and eventually gave rise to the establishment of the Pasteur Institute to carry on his research in this and in many other fields. The famous saying, "chance favors the prepared mind," is attributed to Louis Pasteur.

Opened November 14, 1888, the Pasteur Institute buildings are across the street from the museum. The institute was established through an international subscription on the initiative of Louis Pasteur himself in order to expand facilities for immunization against rabies, to continue his research on infectious diseases and transmit the knowledge that came from this research. The institute's website (*20*) provides information on the museum (in the French version only) as well as on the present mission of the research arm. It should be noted that visits to the museum are available every week-day (Monday through Friday) but limited to guided tours at 2, 3, and 4 PM, each lasting one hour. About 30 minutes of the tour is allotted to the science mementos room where visitors can wander at their leisure armed with copies of the contents of the display cases in various languages. This is hardly enough time to appreciate the richness of the materials on display, so the visitor would do well to prepare in advance by reading about at least one field of interest (*21*). If your interest is stereochemistry, then a brief introduction to its history and Pasteur's profound influence on this field, along with a laboratory experiment that repeats his discovery, might be more appropriate (*22*).

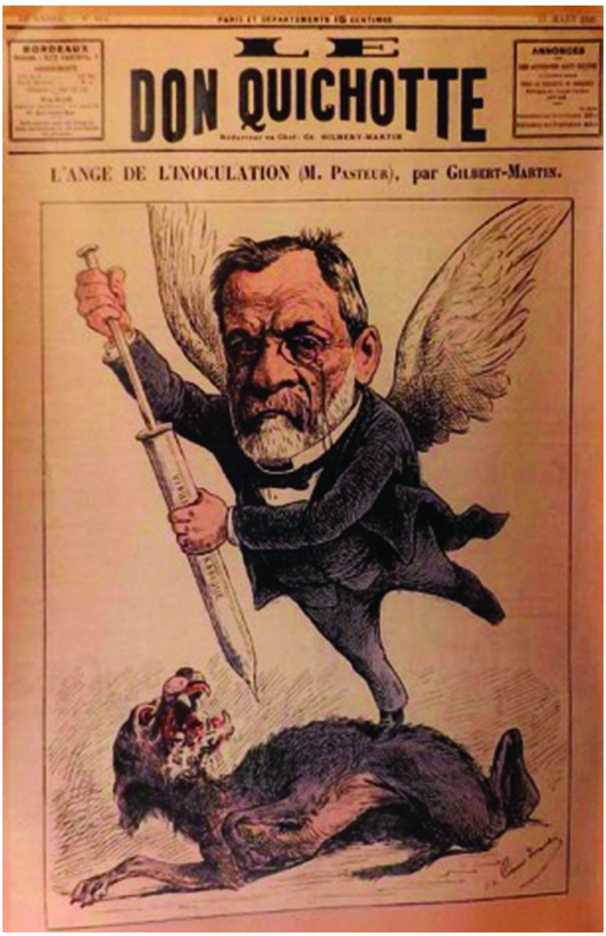

Figure 19. Louis Pasteur depicted as the "Angel of Inoculation" on the cover of the French satirical weekly, Don Quichotte (March 18, 1886). Photograph by Mary Virginia Orna.

Louis Pasteur, even though he was first and foremost a chemist, influenced and even laid the groundwork for many other fields of study in addition to stereochemistry: immunology, germ theory, microbiology and bacteriology. Any one of the books on Pasteur listed in the references will provide an entrée into the life and works of this great man.

If you are interested in wandering farther afield in search of Louis Pasteur's roots, one can follow his footsteps in the Jura region (East-Central France) starting out in the city of his birth, Dôle. There you can visit his birthplace-museum and his father's old tannery (*23*), at 43 rue Pasteur. The museum is open every day from April through October, and weekends the rest of the year. Guided tours are available. There are extensive displays documenting Pasteur's life and work. It should be remembered as you tour this region that Pasteur's life was not all sweetness and light: he suffered academic failure, defeat, ridicule, and controversy, as well as poor health caused by a series of severely limiting strokes.

Moving southwest out of Dôle, the major points of a "Pasteur circuit" are:

- Villers-Farlay: Jean-Baptiste Jupille, a child in the village, bitten by a rabid dog in 1885, was saved by Pasteur's vaccine;
- Salins-les-Bains: Pasteur's paternal family home is located at 60 rue Pasteur;
- Mont Poupet: In 1860, Pasteur conducted a series of experiments here designed to demonstrate the existence of germs in the atmosphere;
- Marnoz: Pasteur's maternal family home;
- Aiglepierre: Pasteur's first school is located here;
- Montigny-les Arsures: Location of a vineyard owned by Pasteur where he carried out his work on fermentation;
- Arbois: Pasteur's home, secondary school, and laboratory are located here. The museum at 83 rue de Courcelles is open every day from April through 15 October, and by reservation the rest of the year (*24*); Arbois is also the capital of the Jura wine region and the site of the Jura Museum of Wine and Vine.

The Paris Sewer Museum (*Musée des égouts de Paris*)

Location: Pont de l'Alma, opposite 93 Quai d'Orsay, Paris, 7th arrondissement. This section is by Roger Rea

Providing clean water for drinking as well as treating waste water has been a challenge for nations for centuries. A tour of the sewers of Paris provides an interesting insight into how water treatment has been managed in this city for nearly seven hundred years. At more than 1,400 miles in length, the sewer system in Paris is the longest in the world, and has been a tourist attraction since the late 1800s. Photographs in the museum show individuals in the late 1800s riding boats through the sewers after attending Sunday church services!

The first vaulted, stone-walled sewers in Paris were built in 1370 by Hugues Aubriot (1320?–1382?). In 1850 Eugène Belgrand (1810–1878) designed the present Parisian sewer and water supply networks. The Paris Sewer Museum is actually part of the working sewer and water-treatment plant for the city, and is entirely underground. Some of the original vaulted, stone-walled sewers are preserved (you get the feeling that you are Jean Valjean in Victor Hugo's novel, *Les Misérables*, as you explore this part of the museum).

A major part of the museum tour takes you through exhibits giving the history of the water cycle and the ways that cities struggled to get safe drinking water as well as treat the sewage so as not to pollute or poison their rivers. Sewage treatment as well as wastewater removal and treatment techniques are displayed along with antique and modern machines used to monitor the purity of the water. In the final station of the museum, you will learn how chemists monitor the pH, conductivity, turbidity, ion concentration and dissolved oxygen in the waste water. Paris is rightly proud that its treatment of city waste water has contributed to restoring the Seine as a place where salmon can be caught and consumed without fear of pollution. Figure 20 depicts a part of the museum tour; Figure 21 shows a device that collects material eventually destined for the sewer system.

The museum entrance is located near the Eiffel Tower on the left bank of the River Seine. Tickets can be purchased at the museum itself. Museum admission is also included in the Paris Museum Pass (which gives free admission to over 60 museums and attractions in Paris). The Museum Pass can be purchased at any participating museum; it can also be purchased at most of the major Métro stations in Paris.

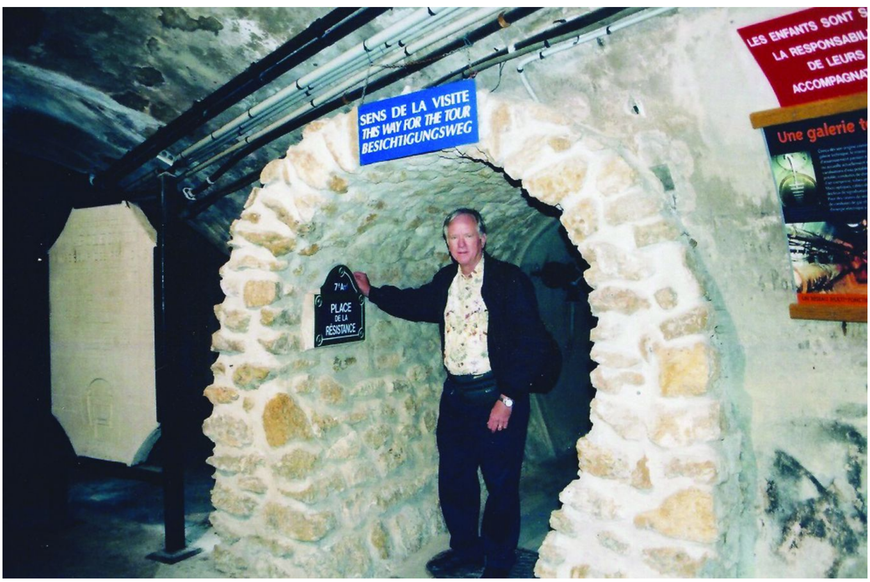

Figure 20. Vaulted Stone Sewer. Photograph of and by Roger Rea.

Figure 21. A common sight on the streets of Paris – the city's attempt to provide "tributaries" for its sewer system (25). Photograph by Mary Virginia Orna.

Beyond Paris: Chartres

If you plan to visit Chartres, a mere half-hour train ride from Paris, the stained glass windows in the cathedral usually command all of the visitor's attention – and well they might. However, only a few steps from the cathedral, at 5, rue du Cardinal Pie, is the *Centre International du Vitrail* (*26*). The only museum of its kind in France (Figure 22), it features collections of ancient and contemporary stained-glass windows, a permanent exhibition explaining the stained-glass windows in the cathedral, and master glaziers' studios. A visit includes a detailed demonstration of the techniques used to create a glass-and-lead window and a guided tour of the exhibitions and stained-glass window collections on show in the museum.

Stained glass is an art form firmly embedded in the history of chemistry. Experimentation in producing the brilliant colors we see today took place over the course of many centuries, utilizing the compounds of copper, iron, lead and tin for the most part (*27*). A visit to this center will give a much greater appreciation of how these works were created and of the science involved.

Figure 22. The International Stained Glass Center, Chartres. Photograph by Mary Virginia Orna.

What Can Be Learned from History?

The history of science in Paris is so rich that an analysis of the pedagogical value of each section would be well beyond the projected size of this chapter. Therefore, let us concentrate on one topic: the many-faceted career of Louis Pasteur.

Pasteur's background deserves a mention. His grandfather was a serf who managed to purchase his own freedom prior to setting himself up as a tanner in the town of Dôle; Pasteur's father, Joseph, continued in this unsavory occupation. Joseph envisioned a better life for his only son and after several failed attempts he managed to have him enrolled in one of the better universities in Paris. However, Louis was early-on considered a mediocre student who did not excel in his chosen field, chemistry. This three-generation unpromising beginning could possibly resonate with students today who find themselves in similar familial and/or academic circumstances.

The turning point in Pasteur's career came when he successfully separated by hand the two optically active forms of sodium ammonium tartrate crystals from an optically inactive mixture of the two, and subsequently demonstrated their respective dextro- and levorotatory properties. He had not been the first to observe the asymmetry of the crystals, but he was the first to apply asymmetry to molecules. Asymmetry had been well-known by René Just Haüy, Eilhard Mitscherlich (1794-1863) and Jean-Baptiste Biot (1774-1862). But the 25-year old Pasteur was the first to realize that the inactive mixture contained mirror-image crystals that were hemihedral, that is, that they contained only half of the number of faces required for symmetry: he had discovered a fact that had gone unobserved by recognized and established peers. The lesson here is to carefully observe a phenomenon for yourself and not rely on the word of others. The lesson is to always be aware of the fact that chance favors the prepared mind and to always keep your mind prepared, your senses alert and sharp, your attitude of one of curiosity and openness to surprise. Historically, there are many examples of Nobel laureates who followed this same pathway to success and fame. Pasteur's classic experiment has profoundly influenced subsequent research in the fields of organic chemistry, inorganic chemistry, stereochemistry, mineralogy, biology and biochemistry.

Later in his career, Pasteur moved into the areas of biology and medicine. His groundbreaking work on chicken cholera and anthrax in sheep, his research on fermentation and germ theory, his tackling of the lethal rabies virus, all deeply affected the health, welfare and economics of 19th century France. The lesson to be learned here is not to confine oneself to one discipline or field: what works in one works in others as well. Although Pasteur was often derided as a "mere chemist," he was able to demonstrate via his powers of observation and cause-and-effect reasoning that the principles of science were universal.

As with everything else, even great heroes have their shadow side. In Pasteur's case, his flaws were largely hidden from the public by a carefully orchestrated "Pastorian" group of family and collaborators who successfully protected his notebooks and papers from outside eyes for almost a century. When they were finally deposited in the *Bibliothèque nationale*, the critical background murmurs heard very feebly and seldom during his lifetime suddenly came to the fore. Examination of his laboratory notebooks demonstrated that he had engaged in gross deception, had exaggerated about the extent of his animal experimentation in many cases, had relied on empirical data rather than on any theoretical basis for most of his work, made hasty generalizations from too few cases (*28*), and engaged in dubious ethics with respect to experimentation on human subjects (*29*). The lesson to be learned here is to practice your own science with integrity and to be very careful to pay homage to the truth no matter what the price: deception will always "out" regardless of the time it may take.

Paris as a scientific "theme" venue is as exciting and unusual as its more famous landmarks. It is hoped that this brief introduction to this other face of Paris will give the reader a deeper appreciation of the riches to be explored here. There are many more reasons to love Paris in any season, not just in the springtime!

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18. By an incredible stroke of good fortune, the salt Pasteur examined was sodium ammonium tartrate, the only tartrate, with the possible exception of the sodium potassium salt, that exhibits this hemihedral behavior (optical activity) and can thereby be resolved of the two crystalline forms. All other tartrate salts, including the two forms of tartaric acid, combine to form crystalline racemic acid and racemates, exhibiting no hemihedrism. Furthermore, even the two sodium ammonium tartrates unite to form a single holohedral racemate above 26 °C, so even the cool Parisian climate worked to Pasteur's benefit—at higher temperatures, he would never have observed the phenomenon.

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Chapter 8

Scientific Florence

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Of the 72 museums in Florence, eight are scientifically oriented and, in addition, there are two historic points of interest. This chapter will tell you where they are and how to get there as well as narrate the importance of the stories they tell in the history of science and natural history.

A Bit of History and Origins of the University of Florence

Two giant figures are part of Florence's scientific history: one, a German immigrant chemist, Hugo Schiff (1834-1915), who spent virtually all of his professional life at the University of Florence; the other, a "native son," who spent the last years of his life in his home south of Florence under house arrest by order of the Vatican. The latter, Galileo Galilei (1564-1642), a native Florentine, is a figure of lore, love, and literature whose work in other parts of Italy, notably Pisa, where he did his famous experiment on gravity, and Padua, where he had an illustrious18-year long academic career, allowed him to return to Florence in triumph under the patronage of the Grand Duke of Tuscany in 1610. It was Galileo's espousal of the Copernican theory that led to his falling afoul of the Vatican and his eventual imprisonment. His daughter, Sister Maria Celeste, gave him great consolation at this period in his life, but sadly, she pre-deceased him by 8 years (*1*).

In Science History: A Traveler's Guide; Orna;

Flashing back to the very year that Dante died, 1321, thanks to a decision of the Florentine Republic, the *Studium Generale* was founded, the true and proper beginnings of the University of Florence. Initially the chief subjects in the curriculum were canon and civil law, literature, and medicine. However, its existence from the very start was held hostage by Popes, Emperors and local princes. For as many times as it was suppressed, it was also reborn, but the university that we know today arose at the end of the 18th century. A few key figures deserve mention: Ugo (Hugo) Schiff, Luigi Rolla, and Angelo Angeli.

The first Chair of Chemistry was established as late as the 19th century and in 1865 the choice of the person to fill it fell upon the German, Hugo Joseph Schiff (1834-1915), a name very familiar even to first-year organic chemistry students today. Born in Frankfurt am Main to a Sephardic Jewish family (*2*), only two years after his arrival he discovered the so-called "Schiff bases," compounds that form through the condensation of an amine and an aldehyde. These bases play a role even now in medical applications such as diagnosis of liver damage. In that same period, he also discovered the "Schiff reaction" that is presently used to determine the fragmentation sequence of DNA. Hated by his colleagues and feared by his students, Schiff, nevertheless was pedagogically innovative in that he set up and maintained a lecture-demonstration table right in his lecture theatre, and never lectured without carrying out the pertinent reactions right in the classroom. This "Aula Schiff," at Via Capponi 9 in the renovated city center university complex (Number 1 in Figure 1), remains as it was first conceived although it is presently closed to the public.

Luigi Rolla (1882-1960) and Lorenzo Fernandes (1902-1977), in 1922, undertook an immense investigation in a search directed at the isolation of element 61, which at that moment took the name *florentium*. This research was historic on account of the enormous quantity of commercial *didymium* used for the fractional crystallizations: almost two tons of the raw material (*3*). Figure 2 is a photograph of Rolla's laboratory during this period. About a decade after these events George de Hevesy (1885-1966) (*4*) and independently Luigi Rolla (*5*), in attempting to isolate the elusive *florentium*, made an unexpected discovery. Without knowing it, they identified the only natural radioactive isotope of an element already known for some time: samarium.

Angelo Angeli (1864-1931) was one of the greatest organic chemists that Italy ever had. He was nominated several times for the Nobel Prize in Chemistry, and his scientific reputation was widespread in Europe. In fact, both Adolf von Baeyer (1835-1917) and Richard Willstätter (1872-1942) saw in him a great future for Italian science and reported that Angeli's work surpassed that of all other Italian chemists, and for its originality and its value it deserved the highest consideration. Angeli's scientific works were characterized by a high level of innovation and originality, mostly on the constitution of azo-compounds.

In the years following Angeli's death, the university suffered heavy setbacks due to the rise of Fascism and the cultural stagnation imposed on the university system. Later, it suffered still more due to the destruction wreaked by World War II. Consequently, academics who were educated in the post-war era were twofold victims of the rigidity of the internal structure of the university's teaching methodology and the difficulty of having interaction and collaboration with their colleagues abroad. Eventually with the advent of younger faculty such as Ivano Bertini (1940-2012) and a few others, chemistry at the University of Florence experienced a rebirth so that by the 1990s, new and important initiatives were under way. For example, in 1999, the Center of Magnetic Resonance (CERM) was founded. The Center constitutes a major NMR infrastructure in the Life Sciences. Flanking laboratories and spin-off institutions have flourished around CERM in the fields of biotechnology and drug discovery.

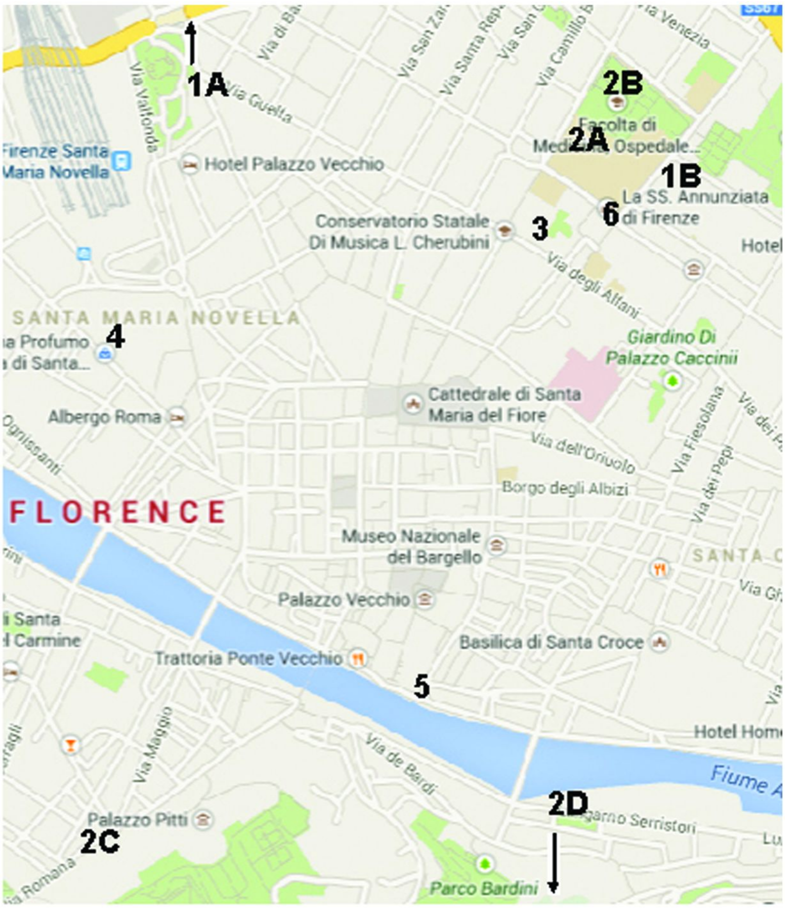

Figure 1. A Map of Central Florence. The numbers correspond to the points of interest outlined in Table 1. (Map Data: 2014 Google).

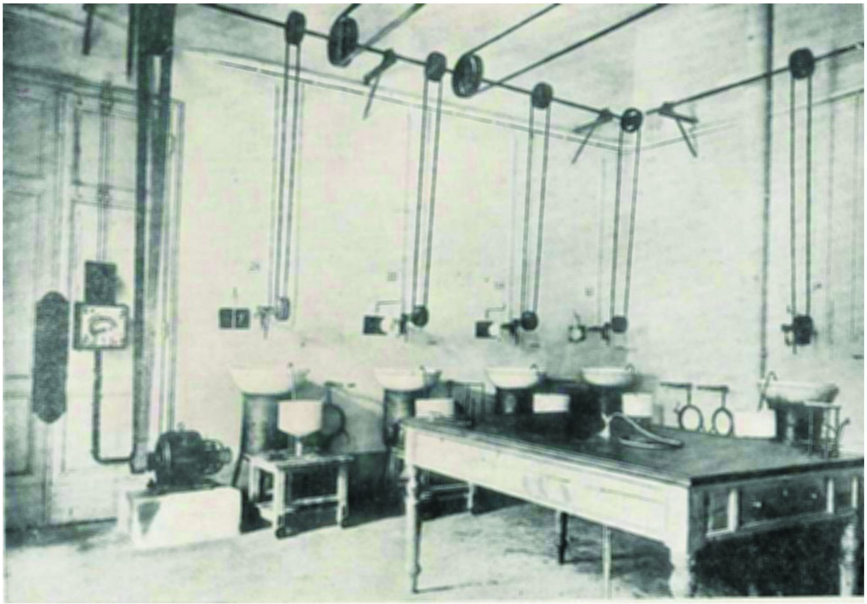

Figure 2. A view of the laboratory fitted out by Luigi Rolla, with public and private funding, for the separation of element number 61 from the monazite sands brought from Brazil. With the kind permission of the University of Florence.

In 2001, the Department of Chemistry moved to the outskirts of Florence and is presently located in the "*Polo Scientifico*" at Via della Lastruccia 13. There, by appointment, it is possible to visit several historic collections (*6*) set up as "Chemical Heritage: Hugo Schiff" in 2008 thanks to funding by the *Ente Cassa di Risparmio di Firenze*:

- The Schiff Collection (the papers, tools, and products with which Schiff made his discoveries);
- The Historic Laboratory Furniture Collection;
- The Bigiavi Collection (over 300 hand-made flasks and test tubes containing samples of synthetic organic dyes);
- The Collection of Historic Scientific Instruments (Scientific instruments built by Giorgio Piccardi for his studies on fluctuating phenomena).

A visit may be booked by email for any weekday morning except holidays (*7*) ; admission is free. By public transportation, take city bus Line 23 from the train station to via Perfetti-Ricasoli (General Electric), and change to Line 59 from via Perfetti-Ricasoli (General Electric) to Department of Chemistry "Ugo Schiff" (end of the line). Driving directions are given in Figure 3.

Table 1. Scientific Points of Interest in Central Florence

No.	*Point of Interest*	*Pertinent Information*
1A	*Polo Scientifico* Via della Lastruccia, 13 Sesto fiorentino	Visit by appointment weekdays. Contacts: laura.colli@unifi.it or marco.fontani@unifi.it; see Figure 3 for driving directions
1B	*Aula* "*Ugo Schiff*" Via G. Capponi, 9	Presently under renovation and not open to the public
2A	Geology; Mineralogy; Paleontology Via la Pira, 4 Tel. +39 055 2757536	Parts of the Museum of Natural History of the University of Florence Hours: M, Tu, Th, F: 9.00 – 13.00; closed W; Sa, Su 10.00 – 17.00 (till 18.00 1 June – 2 Sept); €6; € 3, red.
2B	Botanical Garden "*Giardino dei Sem-plici*" (Garden of Medicinal Plants) Via Micheli, 3 +39 055 2757402	Part of the Museum of Natural History of the University of Florence Hours: Sa, Su, M 10.00-17.00 (16 Oct – 31 Mar) Daily 10.00 – 19.00 (1 Apr – 15 Oct); Closed W; €6; €3, red.
2C	Zoology "*La Specola*" Via Romana, 17 +39 055 2288251	Part of the Museum of Natural History of the University of Florence Hours: Tu-Su 9.30-16.30 (10.30-17.30 1 June – 30 Sept; Closed M Guided tour only; €10; Reduced €5
2D	Villa il Gioiello Pian de' Giullari, 42 +39 055 2346760	Admission by reservation and guided tour only; tickets can be purchased at 2A or 2B ticket desks
3	Museum - *Opificio delle Pietre Dure* Via degli Alfani 78 +39 055 265111	Hours: M – Sa 8.15-14.00 (Th till 19.00); Su & Holidays: Closed Admission: €4
4	Pharmacy of Santa Maria Novella Via della Scala 16	Hours: Daily 10.30 – 19.00 Free Admission +39 055 216276
5	*Museo Galileo* Piazza dei Giudici 1 +39 055 265311	Hours: Daily 9.30-18.00 (Tu till 13.00) Full price €9 – Reduced price €5.50
6	National Archaeological Museum Piazza della SS. Annunziata 1	Hours: Tu-F 8.30-19.00; Sa-Su 8.30-14.00; Closed M Full price €4; Reduced price €2 +39 055 23575

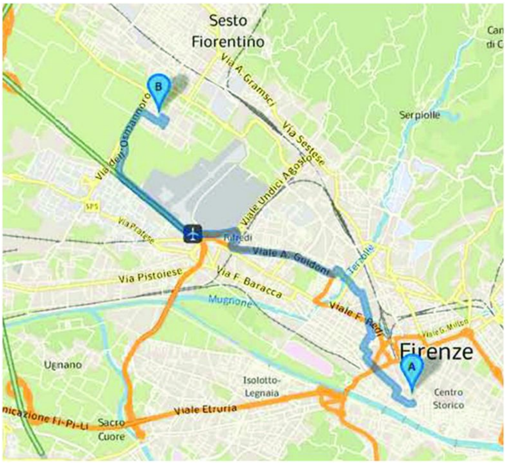

Figure 3. Driving directions from central Florence to the Polo scientifico, University of Florence, Via della Lastruccia 13, Sesto Fiorentino (1A in Figure 1) via Via A. Guidoni, 10.25 km, 20 min. (Map Data: 2014 Google).

The Museum of Natural History − University of Florence

The first collections that eventually comprised the museum appeared thanks to Lorenzo the Magnificent (1449-92). The natural history collections began under the first Medici (particularly Lorenzo) in the family palace in Via Larga (today Via Cavour). The specimens were mixed with art works, as in the classic *Wunderkammern*. For this period, certain knowledge is only available for decorative objects forming part of the Medici collection of the Mineralogy Section. The Museum of Natural History, University of Florence, as we know it today was founded in 1775 by Grand Duke Peter Leopold, although the Botanical Garden dates back to 1545. With its 8 million specimens, it is the most important natural history museum in Italy and one of the greatest in the world.

Consisting of six sections located in one of the world's most beautiful historical cities, the Museum houses specimens of extraordinary scientific and natural value: from the 16th century herbaria to the valuable 18th century waxes, from the fossil elephant skeletons to the collections of brightly colored butterflies, from the huge tourmaline crystals to Aztec artifacts, from the imposing wooden sculptures to the world's largest flower: a context that admirably combines nature, history, science and art.

This museum has three locations as indicated in Figure 1 and Table 1. The Geology and Paleontology section is dedicated mostly to an Italian fossil mammal collection; the Mineralogy and Lithology section consists of about 45,000 specimens, the most important of which are large amethyst geodes, a 151 Kg topaz crystal and a large meteorite collection. Figure 4 is a typical display case in this section (Number 2A in Figure 1). A short walk away lies the Botanical Garden (Number 2B). Here we find one of the oldest botanical gardens in the world, founded in 1545. It has been designated an institution that has living plant collections for scientific research, conservation, exhibition, and education. It has numerous outreach activities for school children as well as the adult population of the area, and in 2008, it initiated a multisensory pathway for the blind (*8*).

While the sections listed above are within easy walking distance of one another, the Zoology section (Number 2C in Figure 1) is located on the other side of the Arno River in the Oltrarno. This section was opened to the public in 1775, making it thereby the oldest scientific museum in Europe. It holds the largest collection of wax anatomical models in the world, developed between 1770 and 1850 for the purpose of teaching medicine, and the models that it exported (Figure 5) influenced medical practice abroad. It also holds over 3,500,000 animal specimens, of which only 5,000 are on view to the public at any one time (*9*).

Figure 4. A typical display case of large mineral specimens in the Mineralogy and Lithology section of the Museum of Natural History, Florence. Photograph by Mary Virginia Orna.

Figure 5. Full wax anatomical figure (nicknamed "Venus Anatomica") demonstrating the female lymphatic system from the Florentine school of Felice Fontana (1730-1803). Semmelweis Medical Historical Museum, Budapest. Photograph by Mary Virginia Orna.

Villa il Gioiello

This residence (Number 2D in Figure 1) is famous because it was the home of Galileo Galilei from 1631 to his death in 1642 (the period of his house arrest by order of the Vatican). Literally called "the Jewel," it is located in Pian dei Giullari, 42 (in the hills south of the city of Florence). It can be reached by city bus, taking Line 12 from the train station to Piazzale Michelangelo (the stop near Porta Romana/Piazza della Calza) and then taking Line 38 from Piazza della Calza (the southern gate of the old town) to Pian de' Giullari (Figure 6 contains driving directions).

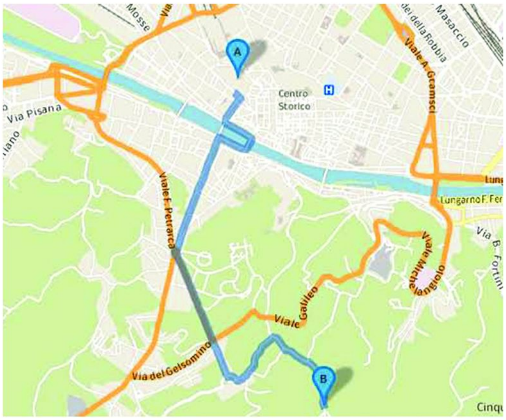

Figure 6. A map showing how to reach the Villa il Gioiello, Pian dei Giullari 42, from Central Florence, via Viale Petrarca, 5.08 km, 14 min. (Map Data: 2014 Google).

Since this residence is considered part of the Museum of Natural History of the University of Florence, tickets are on sale in the following museum sections: Geology and Paleontology and Botanical Garden. Although it is sometimes called "Galileo's house," it should not be confused with other Galilean residences around the city. Figure 6 contains driving directions to "Il Gioiello."

The house is actually adjacent to the Monastery where Galileo's two daughters were Religious. His favorite, Virginia (Suor Maria Celeste), was a great consolation to him prior to her death in 1634. Galileo continued to write and to correspond, and in that he seemed to have great freedom. He was never tortured or thrown into prison, but his movements were limited. He even had assistants during this time, one of whom was Evangelista Torricelli (1608-1647), the inventor of the barometer (*10*).

The Opificio delle Pietre Dure

The semi-precious stones workshop has a four-hundred year history, having been founded in 1588 by Ferdinando I de' Medici, a great patron of the arts. Since that time, the artisans employed in this work have brought the stone mosaic genre to a peak of artistic perfection, rendering the already precious stones even more so, actually priceless, by their incorporation into unique works of art: inlaid tables, mosaic coats of arms, mosaic pieces of flowers, birds, bucolic scenes, and countless other decorative objects (Figure 7).

Figure 7. An example of the decorative style found in the works at the Opifico delle Pietre Dure. Photograph by Mary Virginia Orna.

Of great interest to chemists is the vast collection of semi-precious stones begun by the Grand Dukes' search for the raw materials of which the mosaics and other works of art were made. The search went far and wide so that the collection now includes lapis lazuli from Persia, chalcedony from India, and blood agate from Goa. These grand-ducal stone reserves are so vast that despite widespread use over the centuries, the collection is still abundant today. The museum also has a rare collection of 18th century workbenches. There are also display cases that summarize the laborious phases in the production of a Florentine mosaic.

The Pharmacy of Santa Maria Novella

The Pharmacy is located in a part of the former Dominican monastery of Santa Maria Novella near Florence's main train station. Said to be one of the oldest pharmacies in the world, it is still busily welcoming customers after 800 years of continuous operation.

In a scroll, dated 1381, it is documented that the Dominicans of Santa Maria Novella were selling rose water as a disinfectant, used especially in times of epidemics. The monks cultivated medicinal plants in a garden (*Giardino dei Semplici*), distilling herbs and flowers, and preparing essences, elixirs, ointments, and balms.

Access to the perfumery is through a finely carved portal in stone (Figure 8a) which introduces the visitor to two lateral exedras, containing two marble statues. The small vestibule is in neo-Gothic style, mostly decorated in blue and gold, and gives access to the main rooms: The chapel still retains frescoes attributed to Mariotto di Nardo (active 1394-1424). The museum is a real Renaissance-style gem. It is still possible to buy perfumes, ointments, ancient herbals and handcrafted spirits. The pharmacy claims that each of its products has its own peculiar history. For example, "Acqua della Regina" is an essence that was created especially for Caterina de' Medici who, crowned Queen of France after marrying Henry II, popularized her perfume in the French court.

The old "apothecary," no longer a pharmacy, has become a perfumery and an herbal-medicine shop. It is housed in the monumental edifice just described, with antique décor and furnishings from various eras. It also preserves a valuable collection of scientific equipment, such as thermometers (Figure 8b), mortars, scales, measuring cups, scientific glassware and fine apothecary jars.

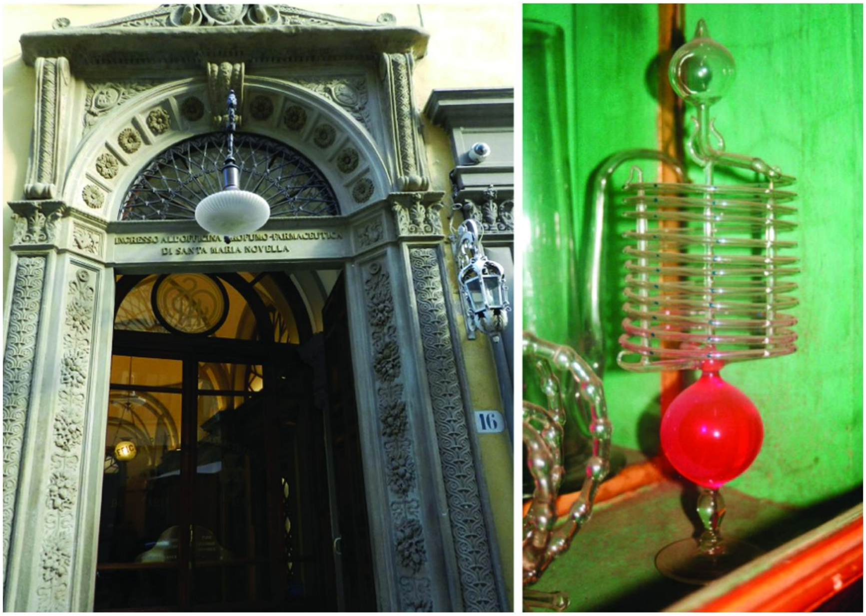

Figure 8. (Left) The entrance to the Pharmacy. Photograph by Mary Virginia Orna. (Right) A fantastic spiral thermometer. Photograph courtesy of Roger Rea.

Museo Galileo

The *Museo Galileo* (until 2010 the *Istituto e Museo di Storia della Scienza*), located on the banks of the River Arno just behind the *Galleria degli Uffizi*, is heir to a tradition of five centuries of scientific collecting, which has its origins in the central importance assigned to scientists and scientific instruments by the Medici and Lorraine families (1562-1859).

In recent decades, the museum the has greatly expanded. Its visibility (Figure 9 shows its façade) has soared thanks to its numerous activities and to the temporary exhibitions it has organized, many of them highly successful on an international level. The museum has thus come to the forefront in the public eye, overshadowing its research and documentation activities; and this despite the impressive growth of the library, the intense promotion of research, and the publication of numerous journals and volumes. Its website enables visitors to explore it as a virtual museum (*11*).

Figure 9. Façade of the Museo Galileo. The museum features many artifacts from the 15th to 19th century, mostly pioneering scientific instruments including world globes, stethoscopes, navigation instruments and telescopes with accompanying videos to the exhibits. Photograph by Mary Virginia Orna.

Among its many unique artifacts, the museum possesses parts of Galileo's right hand which were removed before his body was transported to a new burial place in 1737. A less personal, but no less important, Galileo relic is his original telescope which is on display in the exit lobby (Figure 10).

Another piece on exhibit, that would delight the soul of any chemist, is the Grand Duke Peter Leopold's so-called "Chemistry Cabinet." This self-contained mini-laboratory (Figure 11) was actually only a part of a larger private laboratory. It was left to the Museum of Physics and Natural History when he departed Florence in 1790.

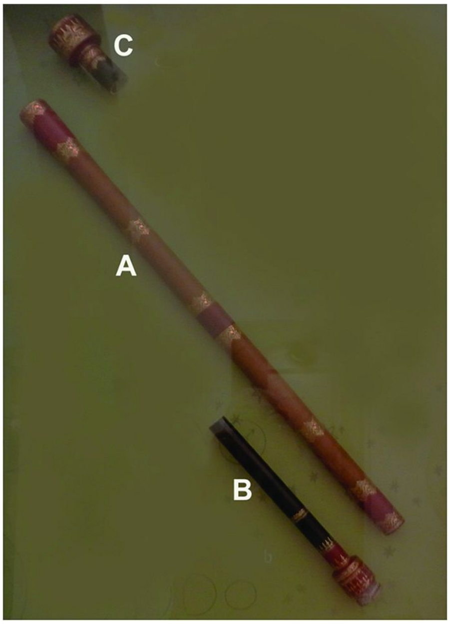

Figure 10. One of Galileo's original telescopes, designed by him to magnify the object being observed by 20X. A. The main body of the telescope; B. The Eyepiece; C. The Objective. Photograph by Mary Virginia Orna.

Figure 11. The Grand Duke Peter Leopold's Chemistry Cabinet. Photograph by Mary Virginia Orna.

Like many other objects in the *Museo Galileo*, the cabinet was severely damaged in the flood of 1966, and some parts of it were lost. Many phials containing substances and specimens, some of them labelled in the duke's own handwriting, survive, as well as the ivory mortars, the inkstand and the candelabra, the tongs and springs. Among the cabinet's accessories, one was particularly curious: the phosphorus extracted by Peter Leopold himself from the urine of soldiers quartered in the Belvedere Fortress.

The National Archaeological Museum

A relative newcomer to the Florentine museum scene, having been inaugurated by King Victor Emmanuel II in 1870, this museum houses Etruscan, Roman, Greek, and Egyptian collections stemming from the penchant of the ruling families of Florence to collect, collect, collect. It is conveniently located near some of the other museums already discussed in this chapter (*12*).

What Can Be Learned from the Scientific History of Florence?

In Florence the union between art and science is reason for extensive reflection and for ongoing discovery. Once thought to be an unlikely combination, a considerable body of literature on the interface and the areas in common of these two disciplines has developed over the past century (*13*). However, Florence anticipated the present age: the "city of art" has always had a "scientific mind."

In the High Middle Ages, chemistry and the applied sciences were the driving force for the impressive economic growth of the city of Florence. For example, with the discovery that urine was very useful as a mordant to dye cloth, the wool guild of Florence at its height directly employed 300 workers and indirectly about a third of Florence's population, producing 100,000 lengths of dyed cloth annually. This trade allowed many Florentine families to become extraordinarily wealthy. Dynasties such as the Peruzzi, the Bardi, and the Medici were so rich that they were able to subsidize England in its war against France.

In more recent times, scientific collections were begun by the Medici family, continued during the Lorraine duchy, and eventually when the Grand-Duchy merged into the newly formed Kingdom of Italy, the mandate to preserve and to strengthen these collections passed to the University of Florence. Some of the museums, such as the Zoology Museum, are historical; others, such as the Museum "Chemical Heritage Hugo Schiff," are brand new. Some of them, such as the Galileo Museum, are completely rearranged, but contain original instruments and artifacts.

In the city that is the symbol of the European artistic Renaissance, it is possible to discover "treasures of science" that one would not expect. This chapter offers a route into the city, following the trail of scientific research.

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Chapter 9

Rome and Northern Italy: Scientific Highlights

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Italy is not only the home of the artistic Renaissance but in large part, it also gave rise to a scientific rebirth as the famous names of Avogadro, Volta, Galileo and Galvani testify. This chapter will explore the scientific treasures of Rome and of the Northern Tier of Italy from Milan to Venice.

Rome: The University of Rome and Its Museums

Rome's scientific heritage is centered largely around its famous university, founded by Pope Boniface VIII in 1303, and except for about a decade of suppression following the sack of Rome (1527-1534), in continuous operation ever since. Its proper name is the University of Rome "*La Sapienza*" (*1*) and if asked where it is located today, it can be found all over Rome. Although its main campus is at the *Città universitaria* (to be described later), its faculty of architecture is housed in a magnificent structure in Piazza Borghese and its faculty of engineering can be found at the cloisters of the church of San Pietro in Vincoli. It also has satellite campuses around Rome and it's outskirts.

From the Baroque Era (17th century) until 1935, the principal seat of the university was the *Palazzo della Sapienza* at Corso del Rinascimento 40 (Latitude : 41.898091 | Longitude : 12.474078), just a few steps away from Piazza Navona in Rome's historic center. Within this building between 1642 and 1660 the architect Francesco Borromini built the university chapel called *Sant'Ivo*(Saint Yves) *alla Sapienza*. A masterpiece of Baroque architecture, the façade can still be seen most weekdays in the courtyard of the building, which now houses the Italian State Archives. The chapel itself is only open on Sunday mornings, at which time one can spy a bevy of photographers, professional and amateur, hovering around the door waiting for the morning Mass to conclude. The lantern is distinct enough and high enough to be visible all over Rome: it is said that it's spiral form was inspired by Borromini's peek at a bee's stinger under the microscope, an instrument invented less than a century before.

Although the main seat of the university was at the *Palazzo della Sapienza*, this was not so for many departments and institutes such as those of the sciences. The Royal Institute of Chemistry was actually rebuilt in Via Panisperna (Latitude : 41.896382 | Longitude : 12.490641) by Stanislao Cannizzaro (1826-1910) in 1871; ten years later, the Institute of Physics moved to the same location. It was at this site in the 1930s that Enrico Fermi (1901-1954) and his team (the famous Boys of Via Panisperna) discovered neutron-induced radioactivity, leading to Fermi's Nobel Prize in physics and to the earth-shaking events surrounding the discovery of nuclear energy. Eventually both institutes outgrew their quarters and moved to the new campus, the *Città universitaria*, located northeast of the Aurelian walls of the city. This campus can be reached by the 310 bus from Termini, Rome's main train station, or by taking either tram 3 or 19.

Gradually many of the departments located at the *Città* developed museums outlining the history of their disciplines within the context of artifacts collected from years of use in research and teaching. Today, the university is home to 19 museums with a common website (*2*) from anatomy (comparative) to zoology, but some of them are closed for renovation and for others, it is necessary to pre-arrange a visit. Each of the museums has its own website, but they are invariably only in Italian, and some are more extensive than others. This chapter will deal with the museums that might be of greatest interest to chemists and practitioners of related disciplines: the museums of chemistry, physics, mineralogy, geology, and the history of medicine. In addition, the university Botanical Garden, and integral part of the museum complex but located on some prime acres on the Janiculum Hill, across the River Tiber, will be described. Table I summarizes their pertinent details.

Table I. Selected Museums of the University of Rome

Museum	*Location*	*Opening Times*	*Contact*
Chemistry	Department of Chemistry Piazzale Aldo Moro N: 41.9010 | E: 12.5122	M – Th 10.00 to 14.00	Contact: M.G. Troiani
Physics	Department of Physics N: 41.9010 | E: 12.5122	By appointment	Contact: G. Battimelli
Geology	Department of Earth Sciences N: 41.9010 | E: 12.5122	M – Th 9.30–13.00	Contact: Prof. Laura Corda
Mineralogy		M – F 9.30–13.30	Contact: S. Biagetti
History of Medicine	Viale dell' Università 34 N: 41.9047| E: 12.5131	M−F 9.30−14.30; M & Th to 17.00	Contact: Prof. L. R. Angeletti
Botanical Garden	Largo di Cristina di Svezia N: 41.8923 | E: 12.4660	M−Sa 9.00−17.30 (18.30 Apr−Oct)	Contact: Prof. Carlo Blasi

The Museum of Chemistry

The museum was established in 1986 and opened to the public in 1992. Situated on the ground floor of the Department of Chemistry, Cannizzaro Building (No. 1 in Figure 1), it has an area of about 250 square meters divided into two rooms, one containing historic artifacts, and the other dedicated to chemical education by welcoming groups of students for interactive chemistry sessions. The museum displays and conserves scientific apparatus, educational instruments, collections of historic chemical substances and documents that belonged to Stanislao Cannizzaro and his group. Worthy of mention are cryoscopes, antique elemental analysis instruments, colorimeters, spectroscopes, and a valuable collection of thermometers that once belonged to Cannizzaro (Figure 2).

Besides the permanent exhibit, the museum has an extensive outreach program for school children. For more information or to schedule a visit, contact Maria Giuliana Troiani at museodichimica@uniroma1.it or telephone 39 06 49913167.

Figure 1. No. 1: Department of Chemistry, Cannizzaro Building; No. 2: Department of Physics, Marconi Building; No. 2a: Department of Physics, Fermi Building; Nos. 3 & 4: Museums of Geology and Mineralogy: No. 5: Museum of the History of Medicine, Viale dell'Università 34.

Figure 2. Precision thermometers dated 1882-1887 from the firm of Goulaz of Paris, some measuring to a hundredth of a degree C. Photograph by Mary Virginia Orna.

The Museum of Physics

The Department of Physics occupies two buildings on the campus. The Marconi Building (No. 2 in Figure 1) contains display cases of antique physics instruments and even a little Foucault's Pendulum; these displays are accessible whenever the building is open. The Museum of Physics proper is located in the Fermi Building (No. 2a), but it is open only by appointment with the Director, Giovanni Battimelli (Giovanni.battimelli@uniroma1.it). It occupies parts of the first and third floors of the building; there is an elevator but it is too narrow to accommodate a wheelchair.

To prepare for a visit, viewing the museum's website would be very helpful. It is well-organized and even though the textual material is in Italian, there are enough visuals to get a good idea of what is there. Pride of place, of course, is given to the Fermi Collection (click "*Sezioni del Museo*" and then "*Collezione Fermi*" to take a virtual tour). Other sections of the museum are Acoustics, Optics, Spectroscopy, Mechanics, Electricity and Magnetism, and Vacuum Pumps.

In the room that houses the Fermi Collection on display are various containers that the research group constructed to hold radioactive samples such as radon-beryllium (gaseous radon and beryllium dust sealed in a small glass tube) used to irradiate their test samples; Geiger-Müller counters; ionization chambers connected to electrometers (to measure activity that exceeded the capacity of the Geiger counters), etc. What strikes the visitor when viewing these early instruments is their extreme simplicity, especially when one realizes the enormous impact that these determinations had on the development of nuclear physics – actually a scientific milestone accomplished with a ball of twine and some sealing wax!

The Museum of Geology

The Museum of Geology is on the first floor of the Department of Earth Sciences (Nos. 3 & 4 in Figure 1), entering the building through the door marked "Mineralogia." The museum specializes in examining and collecting specimens in the sediments of river deltas in central Italy. A museum highlight is its valuable and historic collections of ancient marbles and ornamental stones, the most comprehensive grouping of its kind in the world. The museum contains exhibits including the geological riskiness of living in Italy and a weather station in real time which can be viewed on its website. The captions are only in Italian.

Although regular hours are posted for the museum, the website warns that these may not be observed due to lack of personnel, so they advise contact at museo.geologia@uniroma1.it prior to your visit.

The Museum of Mineralogy

This is the university's oldest scientific museum, founded in 1804. It is the result of devoted and unremitting collecting and it preserves and displays over 33,000 examples of minerals and some other special collections. The museum is a veritable wonderland of giant amethysts, geodes, amber, granite, diamond, agate, calcite, and beryl, among hundreds of other types of minerals.

The Museum of Mineralogy is housed on the ground floor in the same building as the Museum of Geology. The email address to use to arrange an individual visit is sandra.biagetti@uniroma1.it, although on arrival, one can ring the doorbell and gain entrance even though the museum is seemingly closed. While the captions are only in Italian, they are easy to follow because of the similarity of mineral nomenclature in English and Italian.

The Museum of the History of Medicine

The Museum of the History of Medicine (*3*), founded in 1938 by Adalberto Pazzini, has a rich collection of objects of medico-historical interest, many of them original, which allow for reconstructing the evolution of medical knowledge from prehistoric times until the advent of genomic medicine. The museum, designed for educational and informative purposes, features video media and interactive multimedia that allow visitors to explore the main themes of the history of medicine, biomedicine and the relationship between the biomedical sciences and society. The entrance is on the Viale dell'Università just to the right of the "Varco 3" entrance to the university proper.

The museum is divided into three levels:

(1) In the basement it is stated in the brochure and elsewhere that there are environmental reconstructions (pharmacy, laboratory alchemist, garden of medicinal plants) that date back to the original nucleus of the museum; there are valuable collections of apothecary jars, surgical instruments, and votive offerings from the Roman era. However, on my last visit, I would

say that this level is under development and is not, at the time of writing, worth a visit.

(2) The first floor exhibits illustrate chronologically the evolution of medical thought from antiquity to the Scientific Revolution (paleopathology, Egyptian, Etruscan, Greek, Roman, Arab, and Monastic medicine). As the influence of Islam spread through the Mediterranean, Western medicine recovered ancient medical theories, while at the same time learned from the clinical and educational developments of the Arab world. The first medical school in Europe was established at Salerno (10th century). It was an outstanding and inclusive medical institution and a cultural model for medical training – many women graduated from this institution as physicians and went on to write important medical treatises. Following Salerno's lead, medical faculties developed from the 12th century onward, at Montpellier, Bologna, and Paris. The great novelty of medical curricula was the teaching of anatomy. What strikes the visitor is the tremendous emphasis on chemistry in the exhibits – it becomes clear by reading the texts accompanying each exhibit that medicine would never have developed without the concurrent development of chemistry in anesthetics (ether, nitrous oxide), drug development (development of modern pharmacology through applying the principles of synthetic organic chemistry), antiseptic practice (use of carbolic acid, chlorinated water), and the identification of chemical mediators at the molecular level, to name just a few areas.

(3) On the second floor, the exhibits describe the transition from experimental medicine to the recent challenges of biomedicine, genomic medicine and its technological applications (odontology, military medicine, anatomy, surgery, physiology, microbiology, immunology, clinical medicine, pharmacology, neurosciences, molecular medicine, and new technologies). The email address to use to arrange for a visit or to check on unforeseen closure is museo.stomed@uniroma1.it. The exhibits are completely bilingual, in both Italian and English.

The University of Rome Botanic Garden Museum

The *Museo Orto Botanico*, the only one of the university museums not located at the *Città universitaria*, is under the direction of the Department of Environmental Biology. Snuggled on 30 acres at the base and up the slope of the Janiculum Hill, it can be reached by taking the number 8 tram to Piazza Sonnino in Trastevere and then walking about 15 minutes along Via della Lungara. It is the only one of the museums open on Saturdays except for national holidays.

In addition to its collections of palms, gymnosperms, water plants, bamboos, and Mediterranean plants it also has a forest of centuries-old "monumental" trees such as giant Sequoias that one would not expect to see except on the West Coast of the United States. Of special interest to chemists would be the "*Orto dei Semplici*" or the Garden of Medicinal Plants. These are plants that were typically grown in monastery gardens in the medieval period and put to use as herbal remedies for all that ailed a person and, indeed, were often the only remedy available for many ailments. They are arranged in raised masonry flower beds (Figure 3), and each species is labeled with the following designations:

Medicinal part of the plant (in Italian)
Plant family (in Latin)
Genus and species (in Latin)
Common name (in Italian)
Where the plant is found: native or otherwise (in Italian)
Medicinal uses (in Italian)

Figure 3. Left: Medicinal plants in their raised flower beds; Right: Close-up of a plant with its accompanying label. Photographs by Mary Virginia Orna.

In Figure 3, on the right, the plant is labeled:

Medicinal part of the plant: plant parts above ground
Plant family: *Polygonaceae*
Genus and species: *Rumex sanguineus L.*
Common name: blood sorrel or bloody dock
Where the plant is found: native
Medicinal uses: diuretic, laxative, antiscorbutic

The contact address is info-ortobotanico@uniroma1.it for additional information and there is a website for reservations for group or individual tours (*4*) as well as a general web address (*5*) which provides additional information on the garden's activities, including its Seed Bank, which exchanges seeds with other botanical gardens in Italy and throughout the world. There is a modest admission charge.

Centrale Montemartini (Part of the Capitoline Museums)

This museum, while it has nothing to do directly with chemistry might tickle the fancy of an engineer or archaeologist since it is one of the finest examples of creative use of space as well as a monument to industrial archaeology. Situated in the Via Ostiense 106 on the left bank of the Tiber (which some would call the "rust belt" of Rome), it is an extraordinary example of an industrial building transformed into exhibit space. It was originally the first public utility plant in Rome, named after Giovanni Montemartini; now it is the second exhibition center of the Capitoline Museums, containing an outstanding collection of classical sculpture from the excavations carried out in Rome at the turn of the 19th century.

The vast rooms inside the building, in particular the Hall of the Machines, preserve unaltered turbines, diesel engines, and colossal steam boilers from the power plant. This striking backdrop accentuates the translucent clarity and delicate sculpting of the ancient marble masterpieces.

The museum is open Tuesdays through Sundays from 9.00 to 19.00, but check its website (*6*) for its holiday schedule. The full price of admission is €5.50; educational guided tours can be booked separately. To reach the museum, the easiest way is to take the Metropolitana Line B to the Garbatella stop and follow the signs; a ten minute walk takes you to the Via Ostiense, a major thoroughfare. Cross it and walk a short distance to the left and it will be found across a small courtyard. If you ask a Roman for directions or if you take a taxi, ask for ACEA (pronounced ah-CHAY-yah), a utilities company that is one of the major sponsors of Rome's civic museums.

The museum has a catalog in English that would be a worthwhile investment for one who is truly interested in all the treasures housed here (*7*).

Conclusion

Rome is a city rich in history but it contains much more than the Forum, Colosseum, and the Vatican. This sampling of the "other" Rome may whet the appetite of the scientifically-inclined traveler to move off the beaten path to one or more of these sites.

Figure 4. An almost surreal juxtaposition of a "modern" turbine with ancient sculptures at the Centrale Montemartini. Photograph by Mary Virginia Orna.

Northern Italy: Milan to Venice

Spread across the Northern Tier of Italy is a number of interesting scientific sites, some of them associated with famous Italian scientists, and others with the industries that flourished in this area. Florence, in Central Italy, is a special city with a chapter of its own (Chapter 8) in this volume.

The Leonardo da Vinci Museum, Milan

Properly called the *Museo Nazionale della Scienza e della Technologia Leonardo da Vinci*, the museum is located only a few blocks away from Milan's most famous tourist destination, Leonardo's own "*Il Cenacolo*," or "The Last Supper." Situated on Via San Vittore 21 (*8*), the museum is open every day except Mondays, Christmas Eve, Christmas Day, and New Year's Day from 9.30 to 17.00 (to 18.30 on Saturdays and holidays).

The declared mission of the museum is to inspire and change the future by stimulating creativity, curiosity, discovery, and understanding. It does this through its exhibits on materials, transportation, energy, communications, a special section on the art and science of Leonardo da Vinci, a department called "New Frontiers," and outreach to young children.

The museum itself was built originally as a monastery in the 16th century, and then transformed by decree of Napoleon into a military hospital in 1805. It morphed subsequently into an army barracks that was virtually destroyed during World War II bombing raids. In 1953, the site was resurrected as the present museum. Figure 5 shows the interior cloister.

Figure 5. The Leonardo da Vinci Museum of Science and Technology, Milan. Photograph by Marie Sherman.

Considered one of the most outstanding examples of the union of the humanities and science, Leonardo da Vinci holds pride of place here – the original nucleus of the collections is the 130 historic models built by examining and interpreting his drawings. This unique group of artifacts includes flying machines and war machines, but most of all, practical machines for making work easier and taking advantage of the laws of physics, particularly mechanical advantage. Only the Leonardo da Vinci museum at the Château du Clos Lucé in Amboise, France can approach the variety and number of such machines (*9*).

The Educational Silk Museum of Como

Sericulture, the art of silk development and manufacture, began in the Veneto, the large area in northern Italy under the control of the Serene Republic of Venice, in the early 13th century. For many centuries, silk production was a closely guarded secret of the Chinese, who exported their coveted material along the famous Silk Road, and even as silk became more readily available, it was still a high-priced, highly prized commodity that could be used to bribe officials, buy slaves, or pay salaries.

The silkworm is the larva, or caterpillar, of the domesticated silk moth, *Bombyx mori*. It is the cocoon of this larva that is so valuable. The larva is initially fed on mulberry leaves and when it has matured to a certain size, it begins to spin its cocoon, each one of which can contain as much as one kilometer of silk thread. Needless to say, silk production is labor intensive and subject to many problems from larva to loom.

In Como, silk production was a traditional way of life for centuries; in fact, Como was known as the "Capital of Silk." Although the industry experienced its peak in the 1970s, shortly afterwards, it found itself in a losing battle with China and many of the smaller silk producers went out of business. In an effort to preserve the industrial history of the area, a committee was formed to gather the abandoned materials and machines to form a museum that would preserve the history of the industry for future generations. As a result, in 1990 the *Museo Didattico della Seta* (The Teaching Museum of Silk) opened its doors. Situated on Via Castelnuovo 9 in Como, more information can be obtained from its website (*10*) or by email to info@museosetacomo.com.

A model quality and process control laboratory has been set up in the museum (Figure 6) to illustrate how the chemical and physical properties of silk were examined in the industrial setting.

On both the Eastern and Western shores of Lake Como it is possible to follow a "silk route," that is, a network of museums, cultural institutions, historical buildings and archives illustrating the birth and evolution of the silk industry in the environs of Como. In addition to the Educational Silk Museum, on the Western shore there is the *Centro di Gelsibachicoltura* at Cassina Rizzardi, the *Opificio di Carlazzo*, the former Comitti silk reeling mills at Brienno, the Triulzi mills at Tremezzo, Grandi at Lenno, and Erba at Pianello del Lario. On the Eastern shore, two venues of great interest are the Silk Museum in Garlate (in the former Abegg silk reeling mill) and the Civic Museum *Setificio Monti* in Abbadia Lariana, which displays the biggest throwing mill in Europe. Getting around to these farflung places could consume some days of travel on mountain roads of unparalleled beauty.

A valuable reference work on the history of the silk industry in Italy is Luca Molà's "The Silk Industry of Renaissance Venice" (*11*).

Como is also the home of the *Tempio Voltiano*, the Volta Museum. A visit to this site is documented in Chapter 1.

Figure 6. Model Laboratory at the Educational Silk Museum of Como. Photograph courtesy of David Hart.

Padua: A University Town with a Rich Heritage

The University of Padua has a glorious history as the 8th-oldest university in the world. It was established in 1222, after a group of students and teachers moved from Bologna. They set up a free body of scholars, who elected their rector and chose their teachers. Defending freedom of thought in study and teaching became a distinctive feature of the university at a time when such values were not only suspect, but at times criminal.

The novel ideas of empirical and experimental methods along with the teaching of theory changed the cultural and scientific history of humanity. In this atmosphere, Andrea Vesalio, the founder of modern anatomy, as well as the astronomer Copernicus, and the polymath-mathematician Galileo, flourished.

Originally the historical seat of the university was the “Bo Hotel” that was given to a butcher by Francesco da Carrara, lord of Padua, in order to repay him for his supplying meat during the city siege in 1405. Located at Via VIII Febbraio in the city’s pedestrian zone, since 1539 it has been the main seat of the University and is familiarly called the “Bo” (meaning “at the sign of the bull”). At the foot of one of the staircases leading to the upper loggias there is a statue of former student Elena Lucrezia Cornaro Piscopia, who is the first woman in the world to receive a doctoral degree in philosophy in 1678 (*12*, *13*). A magnificent image of this pioneering woman is the centerpiece of “The Great Window” in the main reading room of the Thompson Library at Vassar College, Poughkeepsie, New York (Figure 7). In it, we see the Lady Elena in the very act of receiving the insignia of the doctorate: the laurel wreath, the ring, and the ermine *mozetta*, surrounded by her learned peers and the symbols of the medieval university curriculum: the Trivium and the Quadrivium (*14*).

From the gallery of the ancient courtyard you can go to the *Sala dei 40*, the ancient "*Aula Magna*" (main hall), so called from portraits of some great foreign students. In this room there is Galileo Galilei's desk where he used to lecture. The "*Aula Magna*" is richly decorated with original heraldic bearings and stuccoes by Tommasini (Figure 8). The "Anatomical Theatre," which dates back to 1594, is very special: built by Girolamo Fabrici d'Acquapendente (1533-1619), it was the first permanent anatomical theatre in the world. It is built in the shape of an ellipse with six floors and has more than three hundred seats (Figure 9). In the center is the autopsy table where the professor used to teach (Figure 10). At the end of the lesson the dissected corpses were thrown into the river under the building. Guided tours in English of the Palazzo Bo and other parts of the University of Padua can be booked at the website (*15*). Highly recommended is a tour of the University Botanical Garden, one of the oldest in the world.

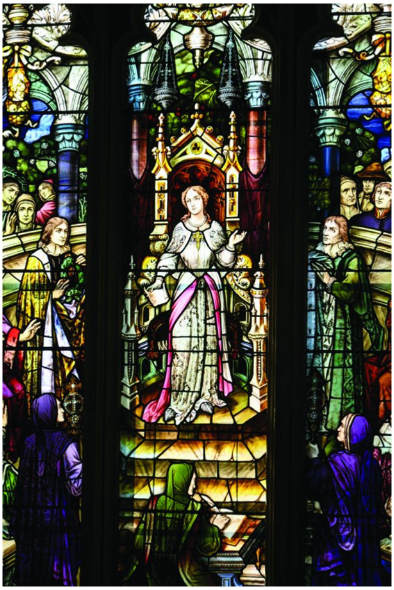

Figure 7. Lady Elena Lucrezia Cornaro Piscopia. ©Vassar College/ Tamar M. Thibodeau -- Tamar M. Thibodeau Digital Imaging Coordinator Office of Communications Vassar College 845.437.7408.

Other cultural landmarks in Padua include "*La Specola*," the original astronomical observatory which was in use from medieval times until the 1930s. Located at Vicolo dell'Osservatorio 5, today it houses a museum of scientific interest containing globes, telescopes and measuring instruments, as well as the largest sundial in Italy. It has very limited hours (*16*) and a visit must be booked in advance at museo.laspecola@pd.astro.it. Padua's Civic Museum (*Museo Civico Eremitani*) is world-class with an archaeological museum on the ground floor and a magnificent collection of Venetian painters on the floor above. It is situated next to another site that should not be missed (but requires advance reservations), the

Scrovegni Chapel (*Cappella degli Scrovegni*), the number one tourist attraction in Padova, where Giotto revolutionized art.

Padua is easily reached since it is on the main train line between Venice and Milan. In fact, since it is only one-half hour away from Venice and the trains are very frequent and inexpensive, it is a less expensive alternative to high-priced Venetian hotels. It is an easily walkable city – there is a pedestrian area right down its center stretching from the Scrovegni Chapel almost to the Basilica of Saint Anthony. It is one of my favorite Italian cities.

Figure 8. Stuccoes in the "Aula Magna" at the University of Padua. Photograph by Mary Virginia Orna.

Figure 9. A Scale Model of the Anatomical Theater at Padua, Side View. Semmelweis Medical Historical Museum, Budapest. Photograph by Mary Virginia Orna.

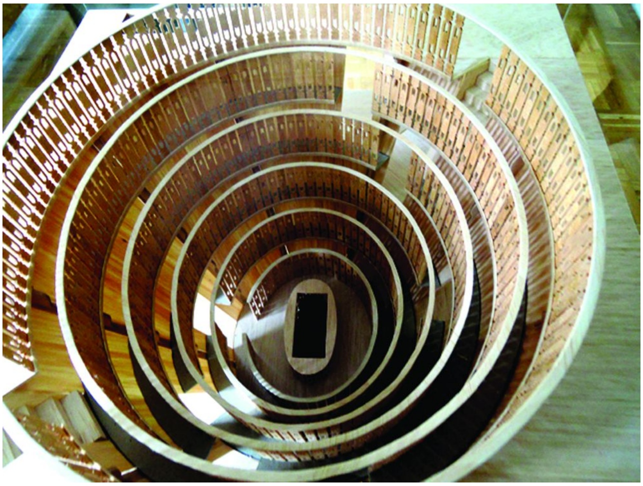

Figure 10. Model of the Anatomical Theater of Padua, Viewed from Above. Semmelweis Medical Historical Museum, Budapest. Photograph by Mary Virginia Orna.

Venetian Glass

Glass origins are shrouded in myth and mystery. Pliny the Elder reports that it was discovered on the shores of the Eastern Mediterranean by some sailors carrying a load of niter who used blocks of said material to build a cooking fire on the sand, thus providing the flux to high-melting silica that would produce the molten transparent semi-liquid we call glass. Another tradition says that glass was accidentally produced by heating sand with kelp, a seaweed whose ash contains large amounts of sodium carbonate, and voilà! Whatever the origins, one must look with skepticism on some of these easy ways of producing a substance that requires temperatures far higher than ordinary cooking or camp fires to produce.

Apart from the myths, archaeological finds indicate that glass appeared somewhere in Mesopotamia and the technique of producing it spread throughout the Mediterranean region. Trial and error gradually dictated the necessity of mixing silica (SiO_2) with a fluxing agent that would allow it to melt at lower temperatures, normally soda (Na_2CO_3), and a stabilizing agent, lime ($CaCO_3$), without which the glass would simply dissolve in water (*17*) . Soda-lime glass seems to be among the earliest glasses known, and the appearance of glass itself can be dated to the second millennium BCE.

The Romans took up the trade of glass-making sometime around 300 BCE. Their first techniques involved casting glass into molds, but gradually their methods become more refined, and these were spread throughout the Mediterranean world. As more and more glass artifacts were found, archaeologists thought that they were objects of trade finding their way into northern Europe by the normal trade routes. Subsequent chemical analysis of many of these objects indicated that the glass artifacts were actually of local origin. So not only the artifacts, but also the art, of glassmaking was a very portable commodity (*18*).

Roman glassmaking declined during the period of the barbarian invasions. Meanwhile, refugees from mainland cities of northeastern Italy managed to tame the salt marshes at the head of the Adriatic and develop, over several centuries, into a seafaring nation optimally positioned to dominate the trade between the East and the West. Thus Venice, in its ascendancy, had access to the high quality materials from Egypt and the Levant that would allow it to develop unique glass materials that were sturdy, colorless, and extremely thin. At one point, Venice was a city in which, from end to end, glass-making furnaces were lighting up the sky.

"The combined factors that provided the perfect environment for the dominance of the Venetian glass industry included: (i) the initial existing glassmaking industry; (ii) the influx of knowledge, skill, and materials from Syria; (iii) the growing importance of Venice in terms of trade, commerce, and culture; (iv) the wider cultural context of the Italian Renaissance in painting, architecture, and the applied arts; and (v) the quality of the raw materials available to the Venetian glassmakers. This resulted in a glassmaking center that produced some of the finest glass ever known and dominated glass technology for centuries" (*19*).

Figure 11. A grouping of the basic tools used by a medieval or Renaissance glass worker. Photograph by Mary Virginia Orna.

As a result of fear of fires, the whole industry was moved by government decree to the Island of Murano in 1291. And there it remains. It has suffered ups and downs over the centuries. Cheap imitations proclaiming "Murano Glass" abound. But the traveler can visit Murano today and even if the glasshouses seem to be specializing in frippery, there are still some very serious (and expensive) works of art coming out of them (*20*). And the best way to see it all, including a detailed history of the art and science of glass, is to visit the *Museo del Vetro*, the Glass Museum. The museum's website (*21*) traces the development of glassmaking in Venice up to the present day. The museum itself documents the techniques, the tools (Figure 11), the chemistry, the innovative artistic and decorative techniques, and so much more. In addition, there are occasional glassblowing demonstrations. While the pedagogical panel boards are all in Italian, there are enough illustrations that the subjects are easy to follow. At the time of this writing, the museum is undergoing major renovation, and in fact, a new building is going up. So presently, only five rooms are open that chronologically trace the technical and artistic aspects of the evolution of Murano glass. The museum plans to reopen in the latter part of 2014.

Located at the Fondamenta Marco Giustinian 8, its normal opening hours are daily from 10.00 to 17.00. To reach the museum from the city of Venice, take the 41/42 vaporetto to the "Museo" stop and then walk along the periphery of the island to your right about 100 yards.

What Can We Learn from History?

By the time that Cannizzaro was appointed to the chair of chemistry in Rome, he had already achieved his major work in chemistry, i.e., his successful promotion of and acceptance of Avogadro's hypothesis by the majority of chemists attending the First International Chemical Congress at Karlsruhe, Germany, in 1860. The purpose of the congress was to try to settle questions regarding the definitions of atom and molecule, how to determine atomic weights, disputes over chemical nomenclature, and many other issues. At the congress, Cannizzaro explained Avogadro's ideas clearly as well as demonstrated their usefulness when applied to organic chemistry. At the end of the congress, many participants departed with a handout containing the outline of the course that he taught at the University of Genoa (*22*), and that seed, once planted, took root and bore fruit upon later reading and consideration. Here we learn the benefits of perseverance.

Surely one of the brightest stars to shine at the University of Rome was Enrico Fermi, the precocious physicist who received his doctorate in that discipline from the University of Pisa at only 21 years of age. In 1927 at age 26 he was elected Professor of Theoretical Physics at Rome, a post created specifically for him, and for the next seven years he was occupied with theoretical studies on spectroscopic data. In 1934 things changed dramatically when he turned his attention to the atomic nucleus, demonstrating that he could accomplish nuclear transformations through neutron bombardment. The official website of the Nobel prize states: "This work resulted in the discovery of slow neutrons that same year, leading to the discovery of nuclear fission and the production of elements lying beyond what was until then the Periodic Table" (*23*). In 1938, Fermi was awarded the Nobel Prize in physics for this work, and immediately thereafter departed Italy for the United States in order to escape Mussolini's Fascist regime. Fermi's original paper on this topic (*24*) hypothesized the first production of the transuranium elements, resulting in expanding the periodic table beyond uranium, but further work has shown that this supposition was incorrect. Nevertheless, Fermi's subsequent brilliant work was enough to win him a place in the periodic table itself – element 100, fermium. He died an untimely death of stomach cancer at the age of 53. Since he carried out all of his work at the Institute of Physics in Via Panisperna, he never occupied any space in the building that bears his name at the *Città universitaria*. And here we learn that even the brightest stars can sometimes lose their luster.

The history of northern Italy illustrates that chemistry, in the form of industrial and manufacturing venues, was very important for the economy, be it for silk production or for glass making. Universities, like that at Padua, played a central role in economic growth, rendering the entire Northern Tier a job center for an entire nation. The industrial venues sprinkled among world-class artistic and architectural centers provide a varied landscape for the interested scientist-traveler.

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Chapter 10

Wonderful Scientific Copenhagen

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Tycho Brahe and Niels Bohr are Copenhagen's scientific stars. The sites where they worked can be visited today as enjoyable diversions from the other major attractions in this beautiful city. A visit to the Round Tower astronomical observatory will round out your interesting scientific tour.

Introduction

"Wonderful, wonderful Copenhagen," are words that make people automatically break into song as they reminisce on Danny Kaye's role as Hans Christian Andersen in Frank Loesser's musical of the same name. Less obvious on most everyone's radar screen are the scientific accomplishments associated with this great island city of the North, although Michael Frayn's 1998 play "Copenhagen" drew the public's attention to one of the city's star scientific players, Niels Bohr.

It is not the role of this essay to cope with Copenhagen's geography, weather, accommodations, and frightfully high prices – there are plenty of guidebooks that do that very well. However, read on, and if you have some scientific interests, they may be completely sated by Copenhagen's scientific history.

Tycho Brahe (1546-1601)

Copenhagen's Stargazing Star

The lives of Nicolaus Copernicus (1473-1543), Tycho Brahe (1546-1601) and Galileo Galilei (1564-1642) neatly span the three centuries of what is generally accepted as the period of the European Renaissance. During this time, Copernicus carried out meticulous daily observations of the motions of the heavenly bodies for decades, coming to draw some startling and literally earth-shaking conclusions early on, but not made public during his lifetime. Tycho Brahe, born only three years after Copernicus' death, continued in his tradition by adding one more improvement: the construction of instruments of observation that were the best possible in his day, prior to the invention of the telescope. Although Galileo is often given the credit for inventing the telescope, the honors actually go to the German-Dutch lensmaker, Hans Lippershey (1570-1619), who patented his design in 1608; Galileo was the first to make use of this powerful instrument (1609 and following) to make his heavenly observations which were to lead to his incredible conclusion: the laws of nature are essentially mathematical. His use of accurate observation and mathematical application truly earned him the right to be called the father of modern science.

What distinguished these three giants in the history of science is the fact that they actually made rigorous observations and interpreted them. The weight of millennia of conventional wisdom, based on Aristotelian doctrine, and sanctioned by a powerful Roman Catholic Church deeply immersed in the anthropocentric and geocentric notion of the universe, would have daunted more timid souls. Tradition (*1*) has it that Copernicus' *opus magnum*, *De revolutionibus orbium coelestium* (On the Revolution of the Heavenly Spheres), was published shortly after his death, and so he never suffered the pain of its condemnation by the church some hundred years later. On the other hand, Galileo experienced the full force of the Roman Inquisition, living under house arrest after his trial for the rest of his days. Tycho Brahe, living in Lutheran Denmark, fell under no such restrictions and was able to carry out his studies freely as long as he retained the favor of the ruling monarch.

Brahe, born Tyge Ottesen Brahe into a noble Danish family, matriculated at the University of Copenhagen at the age of twelve. While a student, Brahe became so enamored of astronomy, particularly by the predicted solar eclipse of August 1560, that it eventually became his life's work. He realized, as did Copernicus almost a century before, that if he were going to accomplish anything of value in astronomy, he would have to devote himself to rigorous observation night after night using the most accurate instruments available – and if not available, improving upon them (*2*). Tycho is the last major astronomer to observe the heavens without the aid of a telescope, which was invented seven years after his death.

A Thermonuclear Event Changes History

Approximately 9,000 years ago, a cosmic flashbulb went off somewhere in our ever-expanding universe, and Tycho happened to be in the right place at the right time to observe it. He was on his way to his alchemy laboratory when, in looking up to the heavens as was his wont, what to his wondering eyes should appear but this evidence of a heavenly explosion whose light took 9 millennia to reach them. The date was 11 November 1572. Brahe, and the rest of western Europe, observed what we now know was a supernova, or exploding star, appearing in the heavens, precisely near the constellation Casseiopeia, in a location where no star had been seen before. It was so bright that it could be observed in broad daylight for two weeks and remained visible for eighteen months, although it changed color from bright white, to red, to dullish gray over this period of time.

At that time, scientists subscribed to the Aristotelian notion of the universe which consisted of a superlunary sphere, above which the universe was perfect and immutable (except for the regular motion of the planets), and a sublunary sphere, the volume of space below the moon, where a changeable earth and all it contained existed. The fact that this object appeared at all signified that it had to be in the sublunary sphere, where things change. Using his new sextant which had arms that were approximately 155 cm long (the longest ever built up until that point), Tycho tried to measure the movement of this new body, but to no avail. In a series of daily measurements, he showed that it did not seem to move against the background of the fixed stars, indicating that it must be a star and not a planet. If it were close by, i.e., sublunary, his new improved instrument would have been capable of measuring its distance from two different reference points, a phenomenon known as parallax. (Our two eyes, with overlapping fields of vision, allow us to estimate the distance of an object using parallax.) Tycho detailed his observations and conclusions in a small book, *De Nova Stella*, published in 1573 (*3*).

Thus, this one event changed the whole paradigm by which we viewed the universe, demolishing the Aristotelian doctrine that it was fixed and immovable. Tycho's astronomical observations were an essential contribution to the scientific revolution, opening the way to the work of Galileo, Johannes Kepler (1571-1630) and Isaac Newton (1643-1727). This one event also changed Tycho's life forever: King Frederik II of Denmark was so captivated by Brahe's scientific expertise in describing and interpreting this event that he persuaded him to remain in Denmark (Tycho had been planning to move on to Basel) by granting him lordship of the island of Hven and generous funding for the purpose of building an astronomical observatory and scientific center – all part of the king's desire to strengthen his kingdom by supporting science.

Heavenly Hven

Thus Hven (or Ven) (*4*), a small island in the Øresund strait to the east of Copenhagen, became one of the finest research centers in the world and remained so for over two decades. With a budget that was estimated to exceed 30% of Denmark's gross national product of the time, Tycho built a state-of-the-art observatory that he called Uranienborg (Castle of the Heavens), elaborately designed with removable roof sections, richly equipped with the best scientific instruments of the time, and housing in its basement what could only be termed a lavish alchemical laboratory furnished with every type of oven and distillation apparatus available. The main floor also contained a large library, study areas, and guest accommodations (*5*).

Unfortunately, vibrations caused by inadequate supports and strong winds limited the accuracy of his observations and thus doomed the utility of Uranienborg as an astronomical observatory. Tycho was forced to base his instruments on sturdier solid stone supports dug deep into the earth to eliminate this problem. Thus a new underground observatory, Stjærneborg (Castle of the Stars), came into being.

Daily trips to and from Hven during June, July and August take about 90 minutes and allow for about a 5-hour visit. The modern Tycho Brahe Museum (Figures 1 and 2) is located in the former All Saints Church near the original Uranienborg site (Figure 3). It has some of his refurbished instruments on display and it is also possible to visit the underground observatory, Stjærneborg (Figure 4), and a reconstructed Renaissance garden. Total cost for the day is estimated at $50.00. For more information, visit the museum's website (*6*).

Figure 1. The Tycho Brahe Museum is housed in the former All Saints' Church, Hven. Photograph: David A. Katz.

Figure 2. Interior of the Tycho Brahe Museum, Hven. Photograph: David A. Katz.

Figure 3. The hedges in the center mark the site of the former castle Uranienborg. Photograph: David A. Katz.

Figure 4. Tycho's Observatory Stjærneborg Today. Photograph: David A. Katz.

More on Tycho

Tycho Brahe's other scientific contributions worthy of note include precise observations on planetary motions, observations on a comet in 1577 that upheld his supernova conclusions of 1572, and the best measurements that had yet been made on the search for stellar parallax. His data was crucial for Johannes Kepler's (1571-1630) later formulation of the three laws of planetary motion.

When King Frederik II died in 1588, he was succeeded by his young son, Christian IV, with whom Tycho had disagreements enough for him to fall out of favor with the reigning monarch – a difficulty that forced his move to Prague in 1597. It was there that he hired Kepler as his assistant, and thus began something of a partnership that some historians feel had a shadow side of jealousy and perhaps even murder. Tycho died in Prague in 1601 and his grave may be visited there in Our Lady of Tyn Church (Figure 5).

There is no doubt that Tycho was a colorful character. Never mind his morganatic marriage, his drunken pet elk, his prosthetic nose, and the mysterious manner of his death. He has continued to fascinate us through the ages, so much so that only recently (November, 2010) his body was exhumed in order to clear up some questions, which have still not been resolved.

Figure 5. Marker above Tycho's Burial Place, Tyn Church, Prague, Czech Republic. Photograph: David A. Katz.

The Rundetårn (Round Tower)

Any visitor to Copenhagen cannot miss the presence of the iconic Rundetårn (sometimes spelled Rundetaarn) (Figure 6), a mid-17th century replacement for Tycho Brahe's Stjærneborg Observatory which was destroyed after his death in 1601. Conceived and planned as part of a purpose-built monumental complex for the university of Copenhagen, this so-called Trinitatis project was to provide the students with a church, a library and an astronomical observatory all-in-one. It was proposed to King Christian IV by Tycho's successor, Christian Longomontanus (1562-1647), in 1625, though it actually took more than thirty years to complete the entire project. The tower, cylindrical in form, was the first to be finished in 1642. The tower served its first purpose as an astronomical observatory for over two centuries, becoming outdated in the 19th century due to light pollution, vehicular traffic , and lack of room for expansion.

Figure 6. The Rundetårn illustrating its attachment to the adjacent building.

The Rundetårn is a remarkable feat of both architecture and engineering. The observatory and library at the top are accessed by a 210-meter long ramp describing 7.5 turns about a masonry core (Figure 7). The reason for this design lay in the idea that a horse-drawn wagon could access the top of the tower in this way (long before the invention of the elevator), transporting heavy astronomical instruments to the observatory and books to and from the library. The observation deck at the top affords a marvelous view of the city.

Today the Rundetårn serves as a concert venue, exhibition center, public observatory and tourist destination (Figure 8).

An interesting architectural and social history feature of the Rundetårn is its two pit latrines, one on the top floor and the other halfway up the tower. The latter has been restored and opened to visitors – for observation only. Modern restrooms were installed in 1902. An information plaque in the tower tells us that the soil from the latrines went into a bricked-up latrine pit so large that it was only emptied twice a century. Therefore, the stench from the latrines was almost unbearable in spite of open windows and double doors. In 1921, when the latrine pit was emptied for the last time, nine loads of soil, reduced to mold, were eased out of the pit. One can sit there and muse about its former use by such celebrities as H. C. Ørsted (1777-1851) or Hans Christian Andersen (1805-1875).

More information about its programs can be found on the Rundetårn's website (*7*).

Figure 7. Accessing the tower via the ramp. Along the outer wall, the ramp has a length of 257.5 meters and a grade of 10%; long the inside wall the ramp is only 85.5 meters long, but with a grade of 33%. Both photographs by David A. Katz.

Figure 8. A great view from the top of the Rundetårn. Photograph by David A. Katz.

Niels Bohr and the Bohr Institute

Niels Bohr's (1885-1962) tenure in Copenhagen may not have been exactly a thermonuclear event, but his 1936 reasoning and calculations regarding the liquid-drop model of the atomic nucleus and the possibility of its fission certainly led to many such events (*8*). By 1939, the scientific community was sufficiently worried about nuclear fission that Albert Einstein (1879-1955) penned a letter to President F. D. Roosevelt (1882-1945) warning him of the possibility of atomic bomb construction using uranium as fuel.

Much earlier in his career, Bohr spent some time in England absorbing ideas regarding atomic structure from such geniuses as Ernest Rutherford (1871-1937) and W. L. Bragg (1890-1971) while he did a post-doctoral stint in physics with the former at the University of Manchester. Returning to Copenhagen, in 1913 he developed his famous Bohr model of the atom by adapting Rutherford's nuclear model to the quantum theory of Max Planck (1858-1947). His model was based upon his realization of the theoretical impossibility of Rutherford's experimentally proven nuclear model of the atom unless, just as Max Planck had quantized electromagnetic energy, mechanical energy must be quantized as well. Bohr's ideas, documented in virtually every introductory chemistry textbook, focused on associating the radii of electron orbits, assumed to be circular, with a set of fixed conditions dictated by quantum theory. He also assumed that the electrons, rather than continuously absorbing or emitting radiation, only emitted or absorbed such energy when jumping from one possible orbit to another. While the model agreed spectacularly with experiment for single-electron atoms, it also formed the basis of later work by others on the many-electron atom. His famous trilogy of papers on atomic and molecular constitution published in the *Philosophical Magazine* (*9*) were one of the reasons cited for his eventual reception of the Nobel Prize for Physics in 1922.

In 1921, the Institute of Physics, the result of a four-year lobbying and fundraising campaign on the part of Bohr, opened its doors with Bohr himself as director. It immediately began to welcome the foremost theoretical physicists from around the world, so much so that it came to be thought of as the "sacred ground" of theoretical physics. Now known as the Niels Bohr Institute (renamed in 1965), with Bohr at the helm it witnessed unprecedented developments in physics over the following decade. Chief among these was Bohr's formulation of his complementarity principle in 1927. Joining together two seemingly contradictory ideas, the wave nature and the particle nature of a quantum of energy, Bohr suggested that waves and particles are complementary ways of describing a measurement – one could say that they are both-and or neither-nor, and that the very act of measurement was the key to determining what we see in our experiments (*10*).

Another slice of history, of a political nature, interrupted the activities of the institute when Bohr, along with many other Jewish and non-Jewish scientists who resisted Nazi oppression, were forced to flee Nazi-occupied countries during World War II.

Bohr's legacy encompasses far more than his contributions to nuclear physics. The latter are cited in virtually every introductory chemistry and physics textbook, particularly his work on the structure of the atom. However, his support for refugee scientists during the war, his advocacy for peaceful uses of atomic energy, his diplomatic efforts for openness and collaboration among nations, are much less cited, but equally important. If you plan to visit the present institute while in Copenhagen, a good preparation would be reading a more detailed biography of this remarkable and complex individual (*11*).

The Niels Bohr Institute is actually a complex of three buildings including the original structure at Blegdamswej 17 (Figure 9), the Rockefeller complex, and the H. C. Ørsted Institute.

Figure 9. The Niels Bohr Institute, Blegdamswej 17. Photograph by David A. Katz.

The website (*12*) describes the various branches, but to make a pilgrimage in homage to Niels Bohr himself, a visit to the original building is in order. There you can visit his office (Figure 10), perhaps sit at his desk, and view the many mementoes to the great physics that occurred here in the first half of the 20th century. One might also contemplate the near-destruction of the institute at the hands of the Danish resistance movement when it temporarily fell into the hands of the Gestapo – it received its reprieve only through the personal intervention of Bohr himself (*13*). It would be wise to contact the Institute first to make an appointment since its thrust is graduate research, occasional outreach to school groups (via Open House, Youth Laboratory, Physics Playroom, etc.), and public lectures in English.

Figure 10. Niels Bohr's Office. Photograph by David A. Katz.

The Carlsberg Brewery

The Carlsberg Brewery was founded by J. C. Jacobsen. The first brew was finished on 10 November 1847. A brief history can be found at the Carlsberg website (*14*).

In 1875 J. C. Jacobson set up the Carlsberg Laboratory to work on the scientific problems related to brewing. It featured a Department of Chemistry and a Department of Physiology. The species of yeast used to make pale lager, *Saccharomyces carlsbergensis*, was isolated at the laboratory. Advances in protein chemistry also took place at the laboratory. It was here that the concept of pH was first introduced by Danish chemist Søren Peder Lauritz Sørensen (1868-1939), the head of the Carlsberg Laboratory's Chemistry Department, in 1909. Sørensen developed the pH scale during his pioneering research into proteins, amino acids and enzymes in a paper that became the basis of today's protein chemistry (*15*). Here is the exact quotation from his paper, an excerpt of which can be found at this site (*16*).

> *The value of the hydrogen ion concentration will accordingly be expressed by the hydrogen ion based on the normality factor of the solution used, and this factor will have the form of a negative power of 10. Since in the following section I usually refer to this, I will explain here that I use the name "hydrogen ion exponent" and the designation* P_H *for the numerical value of the exponents of this power.*

The Brewery is open for tours on the weekend but what remains of the laboratory is not included (*17*). However, a visit could be a pleasurable finish to a day of touring wonderful, scientific Copenhagen.

What Can History Teach Us?

History is not only personal, but is governed by the many unforeseen scientific, political, religious, geographical, meteorological, and even cosmic circumstances that surround each event and each individual. The full effects of all of these types of circumstances can be observed in Copenhagen's wonderful scientific history, and one might wonder if history might have been different if even just one of these factors had changed.

One example could very well be how one seemingly unrelated event leads to another. In 1822, the Englishman Sir John Herschel (1792-1871), while studying the visible spectra of colored flames, remarked that these colors afforded a neat way of detecting extremely minute quantities of substances. Almost four decades later, the Germans Robert Bunsen (1811-1899) and Gustav Kirchhoff (1824-1887) devised an instrument to measure the wavelengths of the colors and thereby succeeded in discovering some new elements such as cesium in 1860 and rubidium in 1861. Just one year later, in 1862, the Swede Anders Jonas Ångström (1814-1874) used the technique of thermonuclear fusion, i.e., observation of the solar spectrum, to show that the sun's atmosphere contained hydrogen and to obtain the spectrum of gaseous hydrogen distributed among many states and energy levels. In 1868 he published the results of a precise, systematic study of absolute wavelengths of over 1,000 solar spectral lines which he expressed in units of 10^{-10} m. This unit is now commonly known as the Ångström (Å). It was Ångström's measurements that the Swiss secondary-school teacher, Johann Balmer (1825-1898), used in 1885 to develop his empirical equation for the series in the hydrogen spectrum that bears his name. And, of course, it was one of the key relationships that led Niels Bohr to propose his model of the atom 30 years later.

Another lesson that history can teach us is that myths and folklore can creep in and obscure what really did happen, so much so that the myth becomes better known than the actual facts. A popular story in this regard is that it was Bohr's application of quantum theory to the periodic system that led to the discovery of hafnium (element 72) among the transition elements, whereas many element hunters were convinced that it could be found among the rare earths. An examination of the scholarly literature, however, reveals that several chemists had predicted its appearance among the transition elements (*18*), and that even one chemist correctly predicted its electronic structure (*19*)!

There are so many factors in the Bohr (and related Einstein) story that tell us that things are seldom as they seem. Mass and energy are so intimately related that this relationship can be governed by an equation! Wave and particle behavior mutually exclude one another, but both are necessary for the full understanding of the object's behavior. Whether an object behaves as a particle or as a wave depends on your choice of experimental arrangement for observing it (*20*). The electrons comprising a chemical bond can be viewed as localized or delocalized. One cannot precisely measure the position and the momentum of a particle at the same time. The position of a particle can only be described in terms of probability. Difficulties connected with the idea of relativistic waves led eventually to the postulate that along with ordinary elementary particles, there must be corresponding anti-particles. The numerical smallness of the values encountered in quantum theory renders it of no importance for the large-scale phenomena which we encounter in everyday life; they emerge only in the study of the processes occurring on the atomic scale (*21*). Perhaps these paradoxes can best be summed up by an excerpt from Bohr's obituary:

> *The tentative character of all scientific advance was always on his mind, from the day he first proposed his hydrogen atom, stressing that it was merely a model beyond his grasp. He was sure that every advance must be bought by sacrificing some previous certainty, and he was forever prepared for the next sacrifice (22).*

This observation could most readily be applied to all of life!

Think additionally of how history could have been changed if the supernova of 1572 had not been observed. Or what if Copernicus had spent all of his life in Rome rather than in northern Europe where he made his measurements. How would things be different if the political situation had been more congenial for Tycho Brahe and he never moved to Prague, where he hired Johannes Kepler. History gives us a different perspective on science, and wonderful, wonderful Copenhagen is full of wonderful science as well! Enjoy your visit to these unique sites.

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classical physics. In addition to his other popular writing, notably in *Scientific American*, we can recommend his "Mr. Tompkins" volumes to the interested reader: *Mr. Tompkins in Wonderland* (1939), *Mr. Tompkins Explores the Atom* (1943), and *Mr. Tompkins Learns the Facts of Life* (1953), all published by Cambridge University Press, Cambridge, U.K.

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Chapter 11

Northern Scandinavia: An Elemental Treasure Trove

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More elements have been discovered in Sweden than any other country. In this presentation, an exploration of these elemental sites will also include Norway and Finland, whose elemental work was closely associated with Swedish academia.

Introduction

Excluding the artificial elements, more elements have been discovered in Sweden than any other country due to a fortuitous combination of great mineral wealth and a superb resource of universities and scientists. In order to explore adequately these riches in Sweden, one can visit the major urban centers by train, but a rental automobile is necessary to reach the many outlying rural areas in this expansive country, the fifth largest in Europe. With associated scientific cultures in all of Scandinavia, the total territory to be explored encompasses 20% of the portion of Europe west of Russia.

This compendium (*1*) includes discoveries in Northern Scandinavia: Sweden, Norway, and Finland (Figure 1). Culturally Finland is usually considered to be separate from the Scandinavian countries, but geographically it is included in the "Nordic" countries and western Finland has historically been closely associated with Sweden linguistically and politically. Swedish Pomerania (Baltic Germany) is also discussed because it is the birthplace of Carl Scheele. (Denmark, the other Scandinavian country, is treated in Chapter 10.) Throughout the chapter, enlarged maps are presented of the regions "Middle Sweden," "Southern Sweden," "Southern Finland," and "Southern Norway (*2*). "

Figure 1. Geographical area encompassed in Northern Scandinavia. This region includes Sweden, Norway, as well as southwest Finland and Pomerania (northern Germany) which were historically part of Sweden. (Map created by the authors.)

Table I lists the elements discovered in Northern Scandinavia. Specific addresses are not included in the table, but are given in the main text. Supplementary sites (such as museums) are also included in the main text. Abbreviations for countries are: Sweden: SE; Norway: NE; Finland: FI. As explained in the text, there may be more than one country associated for some elements. However, the list below includes the "main" or "official" sites for the discoveries. (To complete the characterization of these elements, data for sites *outside* Scandinavia are also given in parentheses). The table is organized by original discovery date.

Table I. Chemical Elements Discovered in Northern Scandinavia

Element (Symbol, atomic no.)	*Date Discover-ed*	*Discoverer(s)*	*Location M = mine L = laboratory*
Cobalt (Co; 27)	1735	Brandt	(L) Mint,
Nickel (Ni; 28)	1751	Cronstedt	(L) Mint,
Oxygen (O; 8)	1770	Scheele (shared with Priestley in	(L) Apothecary, Uppsala, SE
Fluorine (F; 9)	1771 (1886)	Scheele (hydrogen fluoride) (Moissan)	(L) Apothecary, SE (M) Garpenberg, SE (L) (Paris, France)
Nitrogen (N; 7)	1772	Scheele (shared with Rutherford in Scotland)	(L) Apothecary, Uppsala, SE
Chlorine (Cl; 17)	1774	Scheele	(L) Apothecary, Uppsala, SE
Manganese (Mn, 25)	1774; 1774	Scheele (discoverer); Gahn (preparation of metal)	(L) Apothecary, Uppsala, SE (L) Mine School, Falun, SE
Barium (Ba; 56)	1774 (1808)	Scheele (distinction between barium and lime) (Davy; metal)	(L) Apothecary, Uppsala, SE (L) (London, England)
Molybdenum (Mo; 42)	1778; 1781	Scheele (discoverer); Hjelm (preparation of metal)	(L) Apothecary, Kőping, SE (M) Bispberg, SE (L) Mint, Stockholm, SE
Tungsten (W; 74)	1781 (1783)	Scheele (Elhuyar; metal)	(L) Apothecary, Kőping, SE (M) Bispberg, SE (L) (Bergara, Spain)
Zirconium (Zr; 40)	(1789) 1824	(Klaproth) Berzelius (preparation of metal)	(L) (Berlin, Germany) (L) 1st Royal Academy, Stockholm, SE
Titanium (Ti; 22)	(1791) (1792) 1887	(Gregor) (Klaproth) Nilson (preparation of metal)	(L) (Creed, England) (L) (Berlin, Germany) (L) University, Uppsala, SE

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Table I. (Continued). Chemical Elements Discovered in Northern Scandinavia

Element (Symbol, atomic no.)	*Date Discover-ed*	*Discoverer(s)*	*Location M = mine L = laboratory*
Yttrium (Y; 39)	1794	Gadolin	(L) University, Åbo (now Turku), FI (M) Ytterby, SE
Vanadium (V; 23)	(1801) 1831	(del Río) Sefström ("rediscovery")	(L) (Mexico City) (L) Mine School, Falun, SE (M) Taberg, SE
Niobium (Nb; 41)	(1801) 1864	(Hatchett) Blomstrand (preparation of metal)	(L) (London, England) (L) University, Lund, SE
Tantalum (Ta; 73)	1802	Ekeberg	(L) University, Uppsala, SE (M) Skogsböle, FI, and Ytterby, SE
Cerium (Ce; 58)	1803	Berzelius and Hisinger	(L) Home, Skinnskatteberg, SE (M) Riddarhyttan, SE
Lithium (Li; 3)	1817	Arfwedson	(L) Kitchen, Stockholm, SE (M) Űto, SE.
Selenium (Se; 34)	1817	Berzelius	(L) Factory, Mariefred, SE (M) Falun, SE
Silicon (Si; 14)	1824	Berzelius, Wőhler	(L) 1st Royal Academy, Stockholm, SE
Thorium (Th; 90)	1828	Berzelius	(L) 1st Royal Academy, Stockholm, SE (M) Løvøya, NO
Lanthanum (La; 57)	1839	Mosander	(L) 2nd Royal Academy, Stockholm, SE (M) Riddarhyttan, SE
"Didymium" (mixture of praseodymium, 59, & neodymium, 60)	1842	Mosander	(L) 2nd Royal Academy, Stockholm, SE
Erbium (Er; 68)	1842	Mosander	(L) 2nd Royal Academy, Stockholm, SE (M) Ytterby, SE
Terbium (Tb; 65)	1842	Mosander	(L) 2nd Royal Academy, Stockholm, SE (M) Ytterby, SE

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Table I. (Continued). Chemical Elements Discovered in Northern Scandinavia

Element (Symbol, atomic no.)	*Date Discovered*	*Discoverer(s)*	*Location M = mine L = laboratory*
Holmium (Ho; 67)	1879	Cleve (shared with Delafontaine and Soret of Geneva)	(L) University, Uppsala, SE (M) Ytterby, SE
Scandium (Sc; 21)	1879	Nilson	(L) University, Uppsala, SE (M) Kragerø, Evje, NO
Thulium (Tl; 69)	1879	Cleve	(L) University, Uppsala, SE (M) Ytterby, SE
Terrestrial helium (He; 2)	1895	Cleve (shared with Ramsay in England)	(L) University, Uppsala, SE (M) Karlshus, NO
Hafnium (Hf; 72)	1923	(Hevesy and Coster in Copenhagen, Denmark)	(M) Kragerø, NO
Rhenium (Re; 75)	1925	(Noddacks in Berlin, Germany)	(M) Knaben, NO

Meet the Chemists

Before we visit the individual sites, it would be helpful to introduce the chemists involved by way of orientation. The early chemists are credited with discoveries at various mines, manufactories, laboratories, pharmacies, and universities, and we will frequently meet up with each at several different sites.

The Three Most Famous Scientists

Arguably the most important chemists were the early researchers Axel Cronstedt, Carl Scheele, and Jöns Jacob Berzelius, who performed their work prior to the mid-19th century.

Axel Frederick Cronstedt (1722-1765), the discoverer of nickel, put the classification of chemistry on a firm basis by his pioneering of the method of blowpipe analysis, which allowed organization of minerals by chemical composition rather than morphology. Thus, Cronstedt was able to declare in his *Försök till Mineralogiens eller mineral-Rikets upställing* ("An attempt at mineralogy or arrangement of the Mineral Kingdom") that he was able to "call Marble a Limestone" (both are calcium carbonate), much to the shock of other early mineralogists who classified minerals on the basis of external characteristics only. Cronstedt's duties as administrator of Sweden's mines took him all over the country.

Carl Wilhelm Scheele (1742-1786) was born in Pomerania (northern Germany, then a province of Sweden), but at an early age moved to Sweden where he preferred to work in the seclusion of his pharmacy, even though he was eventually invited to be director of the Berlin Academy. His skill and reputation so impressed the scientists of the Swedish Royal Academy of Sciences that they elected him a member even though at the time he was merely a pharmacist's apprentice. His main discoveries were made at Kőping and Uppsala. Scheele is credited with the discovery or co-discovery of eight elements, including oxygen which he had prepared before Joseph Priestley (1733-1804) made his own announcement.

The scientific giant was Jöns Jacob Berzelius (1779-1848), who "seemed to be at the center of every new scientific discovery (*3*)." He was elected secretary of the Swedish Academy of Sciences and began publishing his own *Årsberättelser öfvre Vetenskapernas Framsteg* (Annual Surveys of Progress in the Sciences). These were published in German in his *Jahres-Bericht*, which was primarily responsible for his growing fame on the Continent; it was Friedrich Wőhler (1800-1882), earlier his postdoctoral student and life-long friend, who translated Berzelius's writings. In his journals he single-handedly reported and evaluated all of the recent publications, and advanced his own scientific ideas.

Other Early Chemists

The precursor to Cronstedt was Georg Brandt (1694-1768), who was the first to probe scientifically the nature of metals, i.e., what constituted a separate new metal and how it differed from an alloy. From his copper mines in Riddarhyttan he extracted a new metal he called cobalt, the first metal discovered since the days of Paracelsus (1493-1541) and Agricola (1494-1555).

Anders Gustaf Ekeberg (1767-1813) discovered a new metal he called tantalum in minerals from both Ytterby, Sweden, and Skogsböle, Finland. Ekeberg performed his work at the original chemistry building at the University of Uppsala.

One of Berzelius's students, Johan August Arfwedson (1792-1841, who was an officer of the Royal Bureau of Mines at Stockholm, discovered lithium by investigating the loss of weight in the analysis of a lithium mineral from Űto, an island near Stockholm.

A contemporary of Berzelius, Carl Gustav Mosander (1797-1858), was a medical student who studied under him. Mosander investigated cerium (which had been discovered by Berzelius and Wilhelm Hisinger, 1766-1852), and discovered lanthanum, terbium, erbium, and didymium, which was later found to contain praseodymium and neodymium by Carl Auer von Welsbach (1858-1929) in Austria. Mosander performed his work at the second site of the Swedish Academy of Sciences in Stockholm.

Johan Gadolin (1760-1852) was a professor of chemistry at Åbo (now Turku), Finland. Gadolin discovered yttrium there when Finland was part of Sweden. The source of his mineral was from Ytterby, Sweden. Yttrium was the first of the rare earths to be discovered.

Nils Gabriel Sefström (1787-1845) "rediscovered" vanadium from a magnetic mountain in Taberg, Sweden (it was originally discovered by Andrés del Río (1764-1849) in Mexico City). Sefström performed his work in Falun, Sweden.

Later Chemists of Northern Scandinavia

Lars Fredrik Nilson (1840-1890) discovered scandium at the "new" university building at the University of Uppsala (the "Philologicum"). The source of the mineral was various mines in Norway.

Also at the "Philologicum" Per Teodor Cleve (1840-1905) discovered helium simultaneously with William Ramsay (1852-1916) at University College, London. The source of the helium, for both Cleve and Ramsay, was cleveite, from Karlshus, Norway.

Christian Wilhelm Blomstrand (1826-1897) prepared the first pure niobium sample at the University of Lund. His work contributed significantly to the understanding of the niobium/tantalum controversy; these two elements were confused for decades because of their chemical similarities.

Exploring the Scientific Sites

Finding sites in urban areas is relatively easy, because dedicated GPS receivers and smartphone Google Earth apps can locate them quickly by address. However, travel in Northern Scandinavia often involves sites without a specific address. Additionally, the beautification programs discourage road signs, and frequently key intersections are unmarked. This difficulty could be solved by abundant maps in this presentation, but space restrictions do not allow this. Two city maps are presented here of Stockholm and Uppsala, as well as four regional maps. In this chapter specific reliance is put on textual directions and geographical coordinates. These coordinates are given with a precision of 0.0001 degree (which gives a resolution of ca. 11 meters latitude, and ca. 9 meters longitude). Sometimes Google Maps Street View is especially helpful, and is mentioned in the text when applicable to rural areas. The first region will be Middle Sweden (see Figure 2).

Figure 2. Stockholm is the starting point for all sites in Middle Sweden. Map prepared by authors.

Stockholm and Environs

Figure 3 presents a map of Stockholm with scientific sites identified.

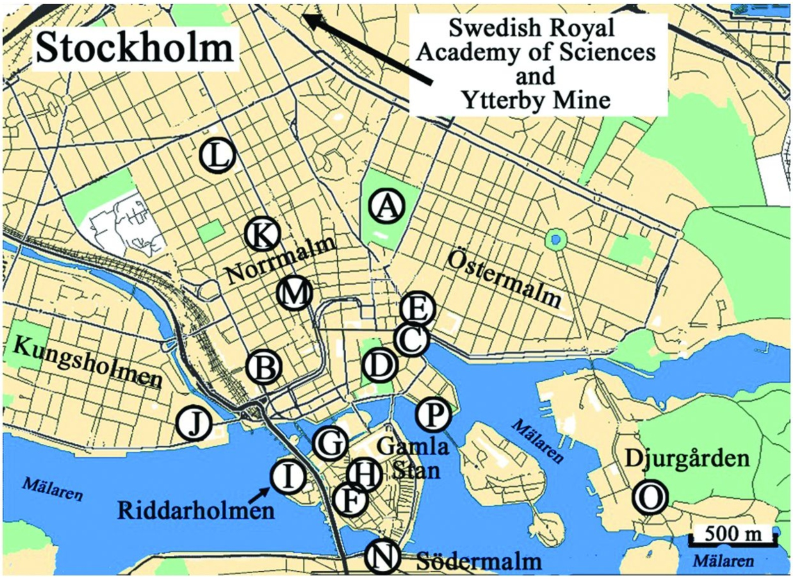

Figure 3. Scientific locations in Stockholm, Sweden. Sites are described in the text. (Map prepared by authors using data procured in their travels.)

Statues and Medallions

Upon arriving in Stockholm, the Humlegården ("Hops Garden"), identified by A in Figure 3, is a pleasant place to relax in Stockholm. This 300x400 meter tract of rolling well-manicured lawns with large trees is a popular site for social gatherings. The garden can be found on the west side of 22 Sturegatan (N59.3390 E18.0728), 1 km northeast of Stockholm Central, the main train station (N59.3308 E18.0590; B, Figure 3).

Two statues of important scientists may be found in the Humlegården. A huge bronze statue of Carl von Linné (1707-1778) was erected by Johannes Frithiof Kjellberg (1836-1885) in 1885. Linné (Latinized to "Linneaus,") performed his studies in Uppsala but was famous throughout Sweden, as well as all of Europe, for his comprehensive binominal nomenclature utilizing *Genus* and *species*. Linné depended on external characters such as color, texture, shape variations, etc. He was aware that his taxonomy was "artificial" – he once stated "Deus creavit, Linnaeus disposuit" (God created, Linnaeus organized) (*4*) – but fortuitously his method of "counting pistils and stamens" or "describing teeth and bones" actually reflected deeper relationships, viz., eventually the sequence of evolution and even the genetic code itself. Moving from the Animal and Plant Kingdoms to the Mineral Kingdom, Linné attempted this method, again using external characteristics such as form, color, or hardness, but here the system failed. To the consternation of Linnaeus, Axel Cronstedt showed that chemical composition was the key to the classification of minerals.

Two hundred meters to the northwest, in the Humlegården (A, Figure 3) is a bronze statue of Carl Scheele, crafted in 1892 by Johan L. H. Börjeson. Scheele is in a reflective pose, seated with his retort and oven at his feet. Scheele discovered more elements than any other Swede – and in fact more natural elements than anyone else in history. Like Linnaeus, Scheele spent most of his life outside of Stockholm.

The third statue, appropriately enormous, is of a scientific giant – Jöns Jakob Berzelius (Figure 4) in the Berzelius Park (Berzelii Park 9, N59.3327 E18.0750; (C, Figure 3), ½ km south of the Humlegården. Berzelius is arguably the most famous chemist that Sweden has produced. Unlike Linnaeus and Scheele, Berzelius spent most of his professional life in Stockholm.

Kjellberg, Linnaeus's sculptor, also fashioned a medallion of Axel Cronstedt which may be viewed in the Gamla Jernkontoret (Large Iron Office) at Kungsträdgårdsgatan 6, (N59.3308 E18.0728; D, Figure 3), ¼ km south of the Berzelii Park.

Berzelius' First Important Laboratory

Just north (200 m) of Berzelius's statue stood his first laboratory, which was called the "German Baker's House" at the corner of 9 Nybrogatan and 14 Riddargatan (N59.3343 E18.0770; E, Figure 3). This laboratory was literally fashioned from the kitchen of his apartment living quarters. Here he performed his famous atomic weight research from 1809 to 1819. His student, Johan Arfwedson, who discovered lithium, also worked in this laboratory. This apartment was owned by Wilhelm Hisinger (1766-1852), with whom Berzelius discovered cerium (see Skinnskatteberg below). The original ramshackle dwelling no longer exists – it was torn down in 1907, and its site is now occupied by Jerns, a fashion shoe store. It is always interesting to ask the present occupants if they are aware that a famous chemist once lived and performed world-famous research at their present site – usually this news is met with open-eyed amazement!

Figure 4. Surrounded by begonias and day lilies, this statue of Berzelius in Berzelii Parken is a commanding figure. It was fashioned by Carl Gustaf Qvarnström (1810-1867) and the park was dedicated in 1858. This was the first full statue sculpted of a Swedish scientist. (Photograph by V. R. Marshall.)

Gamla Stan ("Old Town")

Gamla Stan means "Old Town" and is found on an island (Stadsholmen) ½ km south of Stockholm Central (Figure 3). Gamla Stan is the original city of Stockholm, full of history and old buildings, and today it is a popular tourist site with quaint shops in its narrow alleys. Berzelius moved to the Royal Swedish Academy of Sciences (RSAS) on Gamla Stan (F, Figure 3) from the German Baker's House. This is the original RSAS building at Stora Nygatan 30 – the corner of Stora Nygatan and Schönfeldts Gränd (N59.3240 E18.0695). The building was erected in 1675; the RSAS moved here in 1779, and Berzelius lived and worked here from 1819 to 1828. Here he discovered thorium and prepared elemental silicon and zirconium. Friedrich Wöhler also worked here in 1823-1824; it was actually here that Wöhler performed preliminary experiments for which he became famous in Germany: the isomerism of ammonium cyanate to urea, which disproved the "vitalism" theory of organic chemistry by showing that organic compounds need not come from living beings. On the building today may be seen a plaque showing the alchemical symbol for iron (♂), historically a strong Swedish commodity. The building is used today as the headquarters for the Swedish Young Conservatives ("Moderata ungdomsförbundet").

Urban Hjärne (1641-1724) maintained a laboratory for mining and metallurgical chemistry during the period 1680 to 1682 in this district, ten years before he moved to the Laboratorium chymicum at Gripenhielmska huset (see Serafimer Hospital below), the precursor of the Royal Mint laboratory. Soon afterwards, in 1696, the Royal Mint laboratory was built, and a laboratory (Laboratorium chymicum) was established there in 1727. An efficient forge was available and this is where Georg Brandt prepared metallic cobalt and Axel Cronstedt prepared metallic nickel. The building was demolished in 1784; today the site is occupied by the Parliament Annex. The location is Mynttorget, meaning "Mint square" (N59.3267 E18.0690; G, Figure 3).

Carl Scheele also spent some time in Gamla Stan in a pharmacy on Stortorget ("Grand Square"), the oldest square in Stockholm, dating from 1400. In the middle of the square is a historic fountain, a natural place where people collected water for their homes and businesses. The pharmacy building still exists; it is located at Stortorget 16 (N59.3250 E18.0703; H, Figure 3). Originally (in 1638), the court pharmacist Philip Schmidt offered not only medicine at this address, but also assorted sweets and spiced wine. Scheele worked in this pharmacy from 1768 to 1770. The building is now a trendy Italian restaurant and coffee shop. The owners swear that the basement is exactly the same as it was in Scheele's day, with masonry dating back to the 1600s; the only modification is a modern flush toilet (in earlier years the toilet was outside). In 1721, the Apotek Förgyhllda Korpen (Gilded Raven Apothecary) was set up here, but was moved to another site on Gamla Stan in 1924 (see below).

The Nobel Museum is located on the north side of Stortorget, just a few paces from the Scheele pharmacy (Stortorget 2). Located in the former Stock Exchange Building, this museum presents impressive displays on the history of the Nobel laureates and the life of the founder of the prize, Alfred Nobel (1833-1896).

The present location of the modern Raven apothecary (Apoteket Korpen; Västerlånggatan 16, N59.3257 E18.0688) is 100 m north of the original apothecary, down the hill toward the Mälaren channel. On the door is a sign, "Apothecary on duty. C. W. Scheele." It first appears to be a historic sign alluding to the scientist Carl Scheele, but in fact is describing a modern apothecary "C. W. Scheele" on the mainland, 0.8 km to the northwest, which one can visit for emergencies at odd hours. Customers come and go in the Apoteket Korpen and proceed with the usual business, but several exhibits detailing the history of pharmacies in Stockholm are presented, rendering the site an interesting mini-museum. The first thing one notices is a stuffed raven. A mortar and pestle, weighing 140 kilograms and dating from 1694, was used for mixing and grinding herbal drugs. An old raven fountain, knickknacks, photographs, historic papers, etc., may be viewed. An exhibit announces that "at the end of the 17th century five pharmacies were situated in the city of Stockholm. Today, only one of these is left, Korpen or Raven. The pharmacy was founded in 1674 by Jürgen Brandt." This was the father of Georg Brandt, the discoverer of cobalt! On the wall is a wooden register board, describing all the owners of the Raven Pharmacy, starting with Jürgen Brandt. Four entries down is the name of one Johan Scharenberg, who was the owner when Scheele was employed there.

Riddarholmen

Berzelius's first employment in Stockholm was at Riddarholmen, a small island just to the west of Gamla Stan (I, Figure 3). This was the site of Collegium Medicum, where Berzelius in 1807 was appointed professor of chemical medicine and pharmacy, after he graduated with an M.D. from the University of Uppsala. He had his first tiny laboratory in the Royal Bakery ("slottsbageriet") by the shore (N59.3251 E18.0621), away from the Wrangel Palace (Wrangelska palatset) to minimize the risk of accidental fires in the palace. Although the laboratory/bakery building no longer exists, the palace still stands and now serves as a townhouse and government building. The professorial appointment of Berzelius was providential, because otherwise he might have continued his career as a routine medical doctor and been lost to chemistry (he had been appointed physician to the indigent in Stockholm). Now the main attraction of Riddarholmen, in addition to the Wrangel Palace, is the Riddarholm Church (Riddarholmskyrkan), a tall-spired landmark, dating from the 13th century, visible across the water from Kungsholmen (Figure 5).

Figure 5. View of Riddarholmen (I, Figure 3) from Stockholm's City Hall.(J, Figure 3). The steeple of the Riddarholmen Church is the prominent feature. On this side of the church, on the shore, was Berzelius's first laboratory, located in a bakery, in front of the Wrangel Palace. (Photograph by V. R. Marshall.)

Kungsholmen – Site of the City Hall

The main attraction on Kungsholmen island is the City Hall ("Stadshuset"; Hantverkargatan 1, N59.3274 E18.0548; J, Figure 3). This is the governing center for the city of Stockholm. Built in 1911-1923, it is also the site of the famous Nobel banquets, held in the "Gyllene Salen" (Golden Hall) following the Nobel presentations every December 10.

A century before the construction of the City Hall, the medical institute moved (in 1816) from Riddarholmen across the Mälaren to Kungsholmen. The institute – "Karolinska Institute" – was built on the site of an old glass factory ("Glasbruket"). This institute was established to train army surgeons, and Berzelius moved his teaching responsibilities here. The buildings of the Karolinska Institute still exist (N59.3275 E18.0520; J, Figure 3), 150 m west of the City Hall. (Decades later, in 1945, the Karolinska Institute relocated 3 km northwest to Solna, and today is a famous medical school. The Nobel Assembly at the Karolinska Institute awards the Nobel Prize in medicine). Berzelius had only primitive laboratory facilities while at the medical institute, both on Riddarholmen and Kungsholmen, and he preferred to work in the kitchen of his "German Baker's House" apartment, described above. These buildings on Kungsholmen are now part of the Stockholm governing body, used for meeting rooms (Norr Mälarstrand 4; N59.3272 E18.0520) and other offices of the City of Stockholm (Hantverkargatan 3A-3L; N59.3278 E18.0522).

A particularly interesting attraction on Kungsholmen is the Serafimer hospital (2F Serafimergrand; N59.3283 E18.0520), only 100 m north of the old medical institute (J, Figure 3). This hospital, "Kongl. Lazaret" (Royal Hospital) was founded in 1752 and is still functional. Inside its main alcove is a historical display of hospital equipment and implements. The right wing of the hospital is the original hospital, where Scheele worked in 1770 and actually might have first prepared oxygen. An anecdotal story describes how a student pulled a stunt by posting a sign on the door: "Here Scheele prepared oxygen. When he left he took it with him (*5*)."

The hospital was placed on the original site of the Chemicum laboratorium, where Urban Hjärne worked, before it was moved to the Royal Mint (see above). Even earlier, in 1692, the Gripenhielmska huset (Gripenhielm's house) was used not only for medical purposes but was adapted for chemical work, a forerunner to the Chemicum laboratorium. The owner of the home, Carl Gripenhielm (1655-1694), was a famous cartographer who mapped Sweden and more specifically, the Stockholm archipelago including the area where the Mälaren Lake drains eastward through Stockholm into the Baltic Sea.

Places of Interest in Central Stockholm (Norrmalm)

North of the Stockholm Central train station is the second site of the Royal Swedish Academy of Sciences (Wallingatan 2; N59.3377 E18.0587; K, Figure 3). This is where Carl Mosander performed his research on the lanthanides. Mosander was a student of Berzelius, and like Berzelius eventually attained a position at the

Karolinska Institute. The building at the 2nd RSAS site looks just as it did in the 1800s while Mosander worked there. It is now an office building.

Further north (½ km) is the Observatory Museum (Observatoriemuseet), located at Dottninggatan 120 (N59.3417 E18.0550; (L, Figure 3). This museum, occupying a former 18th century observatory, has several scientific exhibits dealing mainly with astronomy and navigation. Unfortunately, owing to financial restrictions, it is closing its public activities. It once had a fine Berzelius exhibition in 2012-2013, which previously was displayed at a permanent site at the 3rd (modern) Royal Swedish Academy of Sciences (see below). It is disappointing that this exhibit of arguably the most historically important Swedish chemist is not being more actively promoted and celebrated.

The Konserthus (Concert Hall), the site of the Nobel presentations, is located ½ km north of Stockholm Central, at Hötorget 8; N59.3349 E18.0636; M, Figure 3).

South Stockholm (Södermalm)

The Stadsmuseum (City Museum) of Stockholm is located just south of Gamla Stan at Ryssgården, N59.3198 E18.0708 (N, Figure 3). Its exhibits include paintings showing the appearance of historic Stockholm. Of special interest are the paintings of Johan Sevenbom (1721-1784) which include perhaps the best renditions of the Royal Mint where cobalt and nickel were first prepared.

Djurgården and the Scheele Exhibit

East of Stockholm Central (3 km by road) is the Skansen Park, an open-air museum established in 1891 to present the daily lives of Swedes in centuries past. It is found by driving east from the Berzelius statue (C, Figure 3) on Strandvägen for 1 km, and turning right (N59.3318 E18.0933) on Djurgårdsbron (bridge) and continuing south for another km to the park entrance (Djurgårdsvägen 45, N59.3242 E18.0998; O, Figure 3). Public transportation is also conveniently available to reach this site. Djurgården means "animal field" (i.e., zoo) and holds Stockholm's zoological park as well as Skansen Park which has full-size replicas of windmills, dwellings, shops, glass works, streets, gardens, etc., all hosted by hosts and hostesses in period costume. What is particularly fascinating to the chemist is a replica of Scheele's pharmacy, including authentic contributions from Scheele's apothecary in Köping (see below). Inside the pharmacy (Figure 6) are shelves of medicines, hearth and distillation apparatus, furniture, retorts, presses, mortars, scales, preparation tables, flasks, storage bins, all dating to Scheele's time – and hosted by a charming multilingual guide in costume. This park is a fascinating place to visit and should be a "must" in any chemist's traveling plans to Stockholm.

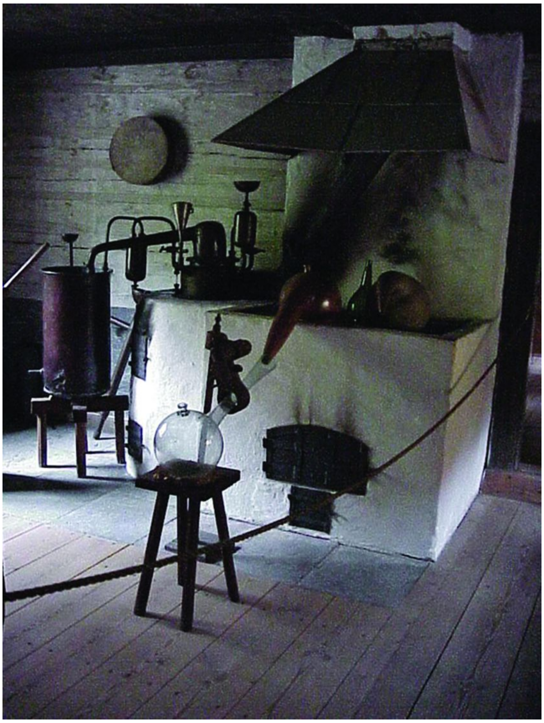

Figure 6. One of the rooms of the apothecary of Djurgården, eastern Stockholm. The equipment has been taken from historic apothecaries, including that of Carl Scheele. (Photograph by V. R. Marshall.)

The Modern Royal Swedish Academy of Sciences (Kungliga Vetenskapsakademien)

This 3rd site of the RSAS is a 5 km drive north from Stockholm Central, located at Lilla Frescativägen 4A (N59.3665 E18.0517). This is not on the map in Figure 3; it is found on the continuation of Roslagsvägen. Inside the Academy there is a prominently placed bust of Alfred Nobel (1833-1896), as well as various portraits of Anders Celsius (1701-1744), Johan Gottlieb Gahn (1745-1818), and others. If one is fortunate, a guide will take visitors to the Nobel meeting room and show how the voting is conducted. The Berzelius Museum, which one could visit a decade ago, was across the parking lot. Unfortunately, this huge and magnificent assemblage of Berzelius's memorabilia is in storage. The collection includes office and living room furniture, his wheelchair, paintings, his molecular models, his chemical equipment, the first voltaic electrolysis apparatus (actually used before Humphry Davy's work), chemical samples, his glassware (he blew all his own glass apparatus himself), crucibles, woodworking tools, blowpipe analysis equipment, crystal models in his mineralogy studies, and his grammar book.

Side Trip to Üto (Map, Figure 2)

Just south (350 m) of the Berzelius statue in Berzelii Park is the boat dock on Södra Blasieholmshamnen (N59.3293 E18.0748; P, Figure 3) from which one can board scheduled boats traveling throughout the Stockholm archipelago (the main Silja lines, from which one may depart for points in Finland and the Baltic states, is located 3 km to the northeast, at Södra Hamnvägen 46; N59.3503 E18.1058). A 50-km cruise from Södra Blasieholmshamnen brings one to the island of Üto (Gruvbruggan Dock, N58.9705 E18.3252). A short walk from the dock (½ km) along a scenic rural path takes one to the museum and iron mine (N58.9670 E18.3292). This is the source of the petalite, a lithium aluminum silicate ($LiAlSi_4O_{10}$) from which Johan Arfwedson discovered lithium in the Berzelius kitchen laboratory at the German Baker's House. In the museum, along with the usual banal tourist souvenirs, the authors were able to purchase authentic samples of petalite, along with informative literature. The mine is closed off with a steel fence, but surrounding the area in the talus (waste rock) beds are very interesting mineralogical specimens which can be abundant in Swedish outcroppings. This mine may be the oldest iron mine in Sweden, dating back to the 12th century. The appearance of the mine is so much like most of the historical mines in Sweden – a quarry flooded with water and looking like an old-fashioned swimming-hole, with rusting equipment around the periphery.

Side Trip to Ytterby (Map, Figure 2)

To a chemist, probably the most famous mine in the world is the Ytterby Mine, the eponymous source for the elements yttrium, ytterbium, erbium, and terbium. The Ytterby Mine is found on Resarö Island, 19 km northeast of Stockholm. In years past, one had to reach Ytterby (meaning "outer village") by boat, but now one can drive to the mine. Driving north from Stockholm (top of Figure 3) on Roslagsvägan, past the modern Royal Swedish Academy of Sciences (not shown on Figure 3), then entering the freeway (E18) north of Stockholm Central (16 km), one turns right onto highway 274 (intersection, N59.4559 E18.1357). Continuing 12 km to Resarö Island, turn left at the sign ("Resarö Island," N59.4172 E18.3099), and then go 2 km further to Långrevsvägen and turn right on Ytterbyvägen (N59.4287 E18.3357). Proceed 1.1 km further to the Ytterby Mine, which is on the left but partially obscured by woodlands (N59.4260 E18.3532).

A short walk up the hill (50 m) takes one to the mine. The mine is closed and covered by brush and trees, but several signs and plaques proclaim the importance of the site. All about the mine rich mineral deposits are visible. Scattered on the ground are shards of high quality quartz and feldspar, which was the original reason for the mine – this material was used in the porcelain trade in Great Britain and Poland. Upon closer inspection, one can see seams of darker minerals, which include the gadolinite $(Ce,La,Nd,Y)_2FeBe_2Si_2O_{10}$) studied by Johan Gadolin in Finland, and yttrotantalite $(Y,U,Fe)_2(Ta,Nb)_2O_8$), one of the sources of tantalum discovered by Anders Ekeberg in Uppsala (see below).

From the vantage point of the Ytterby Mine, there is an inspiring view of the Östersjön (Swedish for Baltic Sea). Frequently one can see tourist ships passing back and forth – this is the main route for Silja lines from Stockholm to Turku and Helsinki, Finland; Tallinn, Estonia; and Riga, Latvia. Indeed, on a trip from Helsinki to Stockholm, the authors viewed and photographed the Ytterby site, dreamily and silently passing by, 1 km away.

If one does not turn left onto Resarö Island, one can continue on 4 km to Vaxholm. A 100-m ferry ride across the archipelago strait takes one to the Vaxholm Fastings Museum on a small fortress island (N59.4029 E18.3587), which has a modest exhibit on the Ytterby Mine. This citadel dates from the 16th century, and was involved in the defense of Stockholm during campaigns with the Danish and the Russians.

Uppsala (Map, Figure 7)

The University of Uppsala, dating from 1477, is the oldest and historically the most important university in Sweden. Uppsala makes a good day trip from Stockholm. It is easily reached by automobile or train, and all sites are comfortable walking distances from the train station (Centralstation, N59.8587 E17.6458; A in Figure 7).

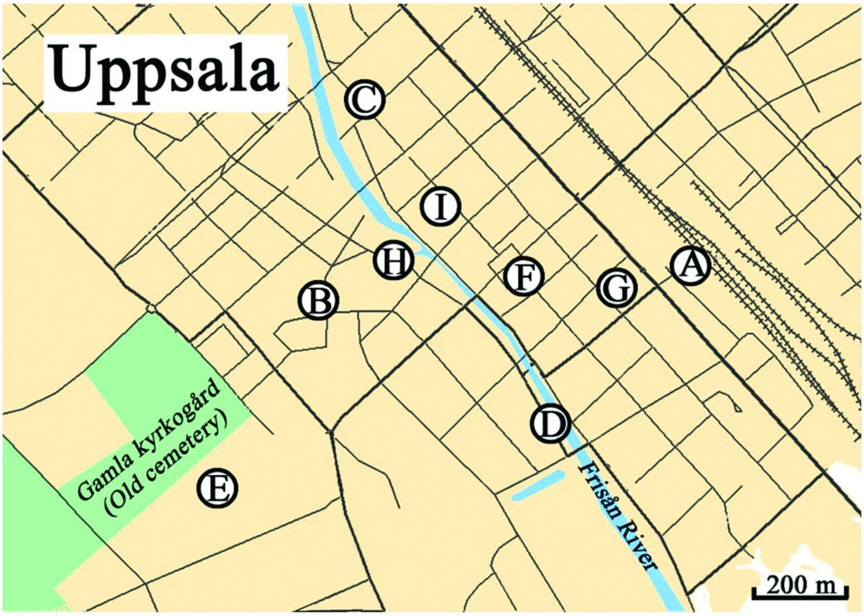

Figure 7. Scientific locations in Uppsala, Sweden. Sites are described in the text. (Map prepared by authors using data collected in their travels.)

Gustavianum

This structure was built in 1622-1625 and was the original center of the university (Akademigatan 3; N59.8579 E17.6318; B, Figure 7). It now serves as a museum with fascinating displays describing science in Uppsala during the 1700s and 1800s, and should be considered the starting point for a scientific tour of the city. Prominently presented in the museum is Torbern Olaf Bergman (1735-1784), who became Chair of the Chemistry Department in 1767. One of his oft cited "discoveries" was Scheele, who worked at an apothecary in downtown Uppsala and whom Bergman mentored. Bergman is noted for a number of several definitive works, including a confirmation of Axel Cronstedt's discovery of the new element nickel (see below under Los), which had been questioned during the pre-Lavoisier era when metals were considered by many to be simply "blends." Some of Bergman's chemicals and mineral specimens are on display in the museum. Also on view in the museum are descriptions of the various chemistry buildings and facilities; laboratory notebooks (including an entry for Berzelius, who was studying for a medical degree in 1799); Celsius's original thermometer; and a gift shop with impressive books (many in English) describing the history of Uppsala. Across the street from the Gustavianum is Uppsala Cathedral (Uppsala domkyrka), the largest church building in Scandinavia.

Linnaeus Gardens

The Linnaeus Gardens (Linnéträdgården) and Museum (Linnémuseet) are found at Svartbäcksgatan 27, N59.8620 E17.6332 (C, Figure 7). This historical garden, with about 1300 species of plants, is maintained as it was in Linnaeus's time, all arranged by according to his pioneering classification system. A statue of young Carl von Linné stands in the garden.

Original Chemistry Building

The original chemistry building of the university stands beside the Fyrisan River. It is located at Västra Ågatan 24, N59.8555 E17.6405 (D, Figure 7). Called the "Laboratorium Chemicum," it was built in 1753 and served the chemistry department until 1858. This is where Anders Ekeberg discovered tantalum, and where Torbern Bergman served. It now is used by the university's Department of Hydrology.

Second Chemistry Building

The 2nd chemistry building stands up the hill (700 m) from the older building, at Thunbersvägen 3, N59.8540 E17.6282 (E, Figure 7). Built in 1860, it is now called the "Philologicum," and serves the liberal arts. Elements discovered here in the 1800s include terrestrial helium, holmium, thulium (Per Cleve) and scandium (Lars Nilson); and titanium metal was first prepared here (Nilson).

New Chemistry Building

The present chemistry building was built in 1904, next to the Philologicum, and has been expanded and modernized recently (Thunbersvägen 5, N59.8542 E17.6273; E, Figure 7). Above the entrance doorway one can view the busts of three celebrities of chemistry in Sweden during its formative years: Tobern Bergman, J. J. Berzelius, and C. W. Scheele.

Scheele's Pharmacy

Uplands Vapen, Scheele's old pharmacy, is located in the center of town at the corner of Stora torget and Kungängsgatan, N59.8583 E17.6395 (F, Figure 7). Scheele was there from 1770 to 1775. Here he discovered nitrogen ("skämd luft"), oxygen ("eldsluft"), fluorine (as hydrofluoric acid), chlorine, manganese, and barium ("heavy spar"). The renovated building is now Åhléns (a "hemköp," or a "home store," a type of domestic department store). Outwardly it appears much as it was in years past. Inside, where people are now buying cosmetics, Scheele was once analyzing natural products that yielded these preparations. (Another Åhléns hemköp will also figure importantly in another elemental discovery; see Falun, Sweden).

Modern Pharmacy

The present Apoteket Uplands Vapen is located in the Svavagallerian Mall (corner of Bredgränd and Dragarbrunsgata; N59.8583 E17.6430; G, Figure 7). It has a permanent exhibition on Scheele, showing his book on Feuerluft (oxygen), wooden canisters, crucibles, a display of his apparatus whereby he prepared oxygen, mineral samples from which he prepared some of his elements, and other memorabilia. Also displayed here at one time was the stone plaque that once graced the old pharmacy (Stora torget and Kungängsgatan) before it became a department store; it can be seen in old photographs. Unfortunately, it is presently in storage under the auspices of the Upplands Museum.

Upplands Museum

The Upplands County Museum (Upplandsmuseet) is located at Fyristorg 2, N59.8587 E17.6345 (H, Figure 7). This museum has interesting historical exhibits not related to science; its significance to chemists is that it owns and stores the Scheele plaque at a remote site, Morgongåva, 40 km to the west. As a courtesy to potential tourists who probably will never see the real thing, it is presented here in Figure 8. This was mounted in the Apoteket Upplands Vapen (G, Figure 7) when the authors visited in the year 2000.

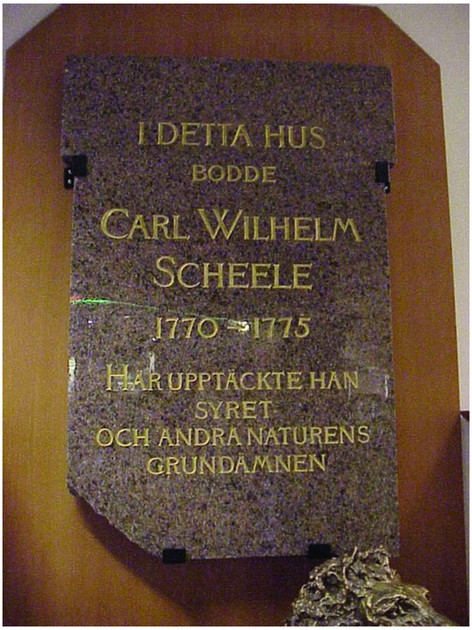

Figure 8. This is the plaque that once resided on the outside wall of Scheele's apothecary (F, Figure 7) before it became Åhléns Hemköp. It translates: "In this house lived Carl Wilhelm Scheele 1770-1775. Here he discovered oxygen and other natural elements.". (Photograph by V. R. Marshall.)

The Celsius Observatory

Anders Celsius, the inventor of the eponymous temperature scale, was an astronomer and his observatory (Celsius huset) may be found at Svartbäcksgatan 9 (N59.8598 E17.6367; I, Figure 7). A plaque on the side of the house commemorates his occupancy. Celsius actually devised a descending scale, with "0" being the boiling point of water. Carl von Linné reversed the scale, with "0" being the freezing point of water.

Köping (Map, Figure 2)

For those interested in Carl Scheele, this is *the* place to visit – the resplendent "Köpings Museum" is almost totally devoted to Scheele. The town of Köping is reached by driving 140 km westward from Stockholm, either by the northern (freeway E18) or southern (freeway E20) route. In either case, exit at highway 250 and proceed to Köping (1 km from E18 or 14 km from E20). "Köping" is pronounced like the English "shopping" with a German umlaut "ö" sound. It means "market-place."

Köpings Museum

To reach the museum, turn east from highway 250 at Nygatan (N59.5090 E15.9925), proceed 80 m and turn right on Jämsvägsgatan and drive 400 m to Östra Långgatan 37; N59.5083 E16.0002). Inside the museum is a full-scale replica of a historic Apoteket called "Scheeles mine" ("in memory of Scheele"), with an astonishing array of exhibits – equipment for preparing medicines, counters, storage bins, balances, books, crucibles, glassware, medicinal preparations, canisters with original labels, full laboratory facilities, samples of herbs used in the preparations, elaborate distillation apparatus, mixing bowls, presses, a sample of Scheele's drug list with his signature – as well as many accompanying paintings and posters describing other discoveries (oxalic acid, glycerin, etc), illnesses treated, maps, a time-line of his lifelong activities, other accomplishments, etc. The elements which he discovered in Köping were tungsten and molybdenum.

Of particular interest to chemists is a showcase displaying minerals from which Scheele extracted and discovered elements, not only at Köping but throughout his career: molybdenglans (molybdenite, MoS_2), a source of molybdenum; brunsten ("brownstone," pyrolusite, MnO_2), source of manganese; flussspat (fluorite, CaF_2), yielding hydrofluoric acid; and scheelit (scheelite, $CaWO_4$), yielding tungsten. The sample of scheelite in the showcase is not the idealized octahedral crystals, but instead the amorphous variety commonly known by local mineralogists as "fruset snor" ("frozen snot"), for obvious reasons. The exhibit also explains how pyrolusite allowed Scheele to procure chlorine (by reacting hydrochloric acid) and barium (as an impurity in pyrolusite). An exhibit also displays Scheele's first independent research in Malmö, where he showed that iron, when reacted with organic acids, produced hydrogen – while Henry Cavendish (1731-1810), the discoverer of hydrogen, had demonstrated the reaction only with sulfuric or hydrochloric acid.

Another model shows how Scheele prepared oxygen, as well as a copy of the original publication "Chemische Abhandlung von der Luft und der Feuer" ("Chemical paper about air and fire").

A fitting end to a tour of the museum is a biography of Scheele, summed up in a famous quotation of his, "Jag kan ej mer än äta mig mätt. Om detta går an i Köping, behöver jag icke annorstädes söka dett." ("I cannot do more than fill my belly, and if I can do so in Köping then I need not go elsewhere.") This was his humble response to those who asked why he didn't reside in a more prestigious location (such as Stockholm), which would be more in line with his incredible fame.

In the guest book of the museum, one can find the signature and comments of Oliver Sacks, author of *Uncle Tungsten* (*6*), 13 October 2003: "Beautiful museum! Lovely to see these memories of my boyhood hero Scheele. . . ."

Scheele's Statue and Grave

Northwest of the Köpings Museum (800 m) is the Köping Church (Köpings kyrka), dating from ca. 1300. Over the doorway is the more "modern" date of 1626 for the present structure. In front of the church is the Scheeleparken

(Scheele's Park; N59.5134 E15.9908). Scheele's statue was fashioned by Carl Milles, a very famous Swedish sculptor who created many sculptures at prominent sites throughout Sweden. Scheele's grave is in front of the church (N59.5132 E15.9905). The epitaph simply reads, "C. W. Scheele. Apotekare Kemist. 1742-1786." Oliver Sacks, during his visit in October, 2003, brought tears to the eyes of Köping's residents when he laid a wreath on Scheele's grave.

The Pharmacies

Scheele actually worked at two different pharmacies in Köping. In 1775 he took over the apothecary owned by the widow of Hinrich Pascher Pohl, who had been pharmacist from 1758 to 1775. The site can be found 300 m southeast of the Köping Church, at Stora Gatan 8-Östra Långgatan 8 (N59.5125 E15.9948) The original building is long gone. This pharmacy, the "Pohl Pharmacy," was actually the site where Scheele discovered the elements tungsten and molybdenum. He was at this pharmacy between 1775 and 1781.

In 1782 Scheele constructed a new pharmacy with a more modern laboratory, at Stora torget 2, (N59.5142 E15.9927, 200 m northeast of Köping Church). He was here during 1782 and 1786, his last workplace and home. This pharmacy, known as Apoteket Lejonet ("The Lion Pharmacy"), burned down on 4 July 1889. The fire, started by a boy playing with matches, swept down Östra Långgatan, destroying 92 houses and rendered 650 persons homeless. Today the Apotekhuset ("apothecary house") building, adorned with reliefs of Scheele and Berzelius, is at this site; it is used for apartments and for community gatherings in the Scheelesalon, the "Scheele Hall." Immediately to the north of the Apotheket is the tourist office (Köpings turistbyrå; Barnhemsgatan 2; N59.5144 E15.9925), which has a very helpful staff who can furnish much useful information about Köping and Scheele.

Skinnskatteberg (Map, Figure 2)

The historic home of Wilhelm Hisinger may be found in Skinnskatteberg, at Herrgårdsvägen 6 (N59.8285 E15.6798). Hisinger and Berzelius were the co-discoverers of cerium, and Berzelius lived for a while in Hisinger's "German Baker's House" in Stockholm (see above). Hisinger's home may be reached by driving north from Köping (37 km) to the intersection with highway 233 (N59.8023 E15.8450); then proceeding 11 km west to the intersection with Kyrksvägen (N59.8288 E15.6868); driving 250 m to Herrsgårdsvägen, then turning left and driving 150 m further.

Iron-smelting in Sweden was practiced as long as 2700 years ago; an ancient site may be found at Röda Jorden (an Ekomuseum site 3 km southwest of Riddarhyttan; accessed off highway 68 at N59.7947 E15.5430), where iron was prepared in small (50-cm) blast furnaces, pits in the ground lined with stone and clay.

By the 1500s much more sophisticated methods of smelting and hammering were being conducted on a large scale; there were several of these operations around Skinnskatteberg. Wilhelm Hisinger's father (Wilhelm Sr., 1727-1790) acquired the Skinnskatteberg property in 1771. Soon the father and son were managing several prosperous iron works in the area and controlled several iron mines (see Riddarhyttan immediately below for the Bastnäs iron mine). Coordination of analysis and other laboratory work was centered in the Hisinger House. This building is now a Forestry Management School (SLU, Sveriges lantbruksuniversitet), and is registered as a Swedish historic landmark (plaqued with a "Byggnadsminnesmärke" – "Building Memorial Mark"). The inside is pristinely maintained, with many of the original furnishings, including an exquisitely decorated ceiling-high oven used for heating the house 200 years ago. A large vase on the mantle is decorated with cobalt blue (see below under Riddarhyttan, where cobalt was discovered).

Riddarhyttan (Map, Figure 2)

Riddarhyttan (meaning "Rider-forge" or "Knight-forge") lies 8 km to the west of Skinnskatteberg. The area is rich with historic iron and copper works, including the famous Bastnäs mine (where cerium was found) and the Brandt copper mines (where cobalt was discovered). Riddarhyttan may be reached from Skinneskatteberg by either (a) driving north 6 km on highway 233 to highway 68 (intersection = (N59.8730 E15.6482), turning left onto 68 and driving south for 11 km; or (b) if one trusts one's skill and Google Maps, one can drive 12 km west on Riddarhyttevägen, a narrow, but paved, road (this road is included in Street View).

In the Riddaryhyttan area, there is a tangle of roads, and sites may be reached by following several different routes. Here it is deemed best to discuss the following Riddarhyttan sites in geographical order, driving south towards Riddarhyttan from the 233/68 intersection mentioned immediately above.

Bastnäs Mine

This iron mine, dating from 1692, was the source of Hisinger's and Berzelius's cerium. Between 1875 and 1888, 4500 tons of cerium ore were extracted from the mine.

Drive south 2 km on highway 68 from the 233/68 intersection, and turn left on a dirt road (intersection = N59.8677 E15.6143); this intersection is not identified by road signs, but it does appear on Google Maps. Proceed 3 km south, and the short road to the mine will appear on the right (Mine = N59.8458 E15.5890).

This old iron mine was very productive in the 1700s and 1800s. Upon arriving, one sees a huge talus pile, and through careful inspection one may find some interesting minerals. Indeed, the authors procured a small, but beautiful 1-cm crystal sample of cherry-colored bastnäsite, (Ce, La,RE)CO_3F (RE = rare earths). This sample when analyzed later in the U.S., proved to contain cerium (29%), lanthanum (26%), and neodymium (6%). The present main U.S. source of the lanthanide elements is Mountain Pass, California; the ore is a rose-colored granular form of crude bastnäsite.

The actual mineral from which Hisinger and Berzelius separated cerium is cerite, a gray heavy mineral, $Ce,RE,Ca)_{10}Fe(SiO_4)_6(Si_3OH)(OH)_3$. The authors procured a sample of this from the Bastnäs Mine and found an impressively rich analysis of Ce (26%), La (11%), Pr (3%), Nd (11%) and Sm (2% Sm). The "light" rare earths (left side of the lanthanide group) are typically found in cerium minerals, while the "heavy" rare earths (right side of the lanthanide group) are found in yttrium minerals, such as those found at the Ytterby Mine.

A billboard sign stands at the mine, "Valkommen till Bastnäsfallet" (Welcome to Bastnäs Field"). The sign explains that this is part of the "Ekomuseum," a collection of outdoor sites maintained by dedicated volunteers. The sign is lengthy, and in Swedish. The mine is closed, although the authors were allowed access by one of the volunteers who had a key to the heavy door. Inside were dark, wet walls – and radioactivity! as evidenced by the authors' Geiger counter. Outside the mine were abundantly scattered chunks of rich hematite, pure Fe_2O_3; occasionally magnetite (Fe_3O_4) could be identified, using our portable boron-iron-neodymium magnets. Surrounding the mine were lush forests, wild strawberries, and an occasional historic shed. During its productive years, the iron ore was taken to the smelter in the winter, when sleds with heavy loads could slide easily on the ground.

When leaving the Bastnäs Mine, one may return north to highway 68 to visit the Old Skilå Works; or if one doesn't mind dirt roads may proceed directly south to Riddarhyttevägen and the Brandt manor and copper mines.

Old Skilå Works

"Skilå" means "splitting" – water is an essential ingredient in smelting, and the stream at this site forked, hence the name. The Old Skilå copper works (N59.8332 E15.5498) on highway 68 are undeveloped and can be easily missed. A parking lot is available for stopping and visiting. Drive 7½ km southwest of the 68-233 intersection to reach this site. The area appears as a wasteland – it was cleared of trees (to make charcoal for the hearths), and the roasting copper ore produced sulfur dioxide which killed vegetation (one may occasionally view similar sights in the Appalachia region of the U.S.). A few crude signs are posted showing names of various hearths, now long gone. An old Swedish book, shown to us by our volunteer guide, described the process centuries ago: a gang of women broke the rocks with hammers, the resulting gravel was roasted on charcoal fires to release sulfur dioxide, and then the roasted ore was heated intensely with charcoal (the smelting process, sometimes repeated several times) to consummate the reduction process and produce elemental copper. The whole process took perhaps two months.

The copper smelting works were distanced from the owners' homes, because of the noxious sulfur dioxide. This is a convenient point to identify, as a road is taken from here to the Brandt Manor site.

Brandt Manor and Copper Mines

This is the discovery site of cobalt. Just north (100 m) of the barren area described immediately above, is an intersection (N59.8330 E15.5519) with Riddarhyttevägen (marked with a "Bäckegruvan" sign). Drive 500 m east on Riddarhyttevägen, and turn right on Centralvägen (intersection = N59.8306 E15.5593). Proceed south on Centralvägen (this is on Street View), then bear west, for 600 m, to find a billboard sign on the right (N59.8273 E15.5537). The information on this sign, again created by volunteers (and may not be maintained), explains how the manor (herrgård) of Georg Brandt (see Stockholm, Raven pharmacy, above) was once just behind, to the north. The manor (not the original, but a subsequent one) was taken down in the early 1900s. A search in the brush exposed the rock foundation of the original manor.

The original copper mines are scattered in the forests to the west and southwest for 200 meters or so. From the Brandt Manor site (immediately above), many mines can be spotted if one is adventurous and does not mind ducking under wire fences and slogging through damp woodlands. (The fences were set up after the mines were flooded, to prevent children from accidentally drowning). Occasionally one can find a half-meter high rectangular stack of stones, which were originally used by miners to stake their claims; they would renew the stack with new stones every year. The mines are now modestly-sized pits, all flooded with water. Various mines are called Pellugruvan, Hedningruvan, Penningruvan, Sörgruve Försök, and Sörgruvan Stollen. (These mines cannot be seen by overhead Google Map shots; the forest is too dense). Cobalt ore was observed from time to time during the copper mining and was considered a nuisance. An incredibly rich vein of cobaltite (3.5 tons) in the late 1800s about 55 m below ground level was procured from the Pellugruvan Mine, 120 m southwest of the Brandt Manor (N59.8273 E15.5500). From this mine the authors procured a cobaltite crystal (CoAsS) measuring 1-cm in diameter.

Also scattered in this area are original stone shacks built by the Brandts. The father (Jürgen) sold his pharmacy business in Stockholm in 1680 and purchased the property; the son (Georg, who was to discover cobalt) was born here and became a world traveler, eventually settling in Stockholm where he did his important chemical work, but frequently visiting the Herrgård where he maintained both a financial and scientific interest. The Brandts were very wealthy, producing copper for the king to help finance the nation's expansionist policies.

One of the mines has been drained (Sörgruvan Stollen; N59.8254 E15.5477) and with our volunteer guide we gained access. On the walls of the mine, minerals of all colors glinted in our flashlights; sometimes green or pink needles were seen growing out of the walls, or turquoise patinas were splashed like a mural of primitive paintings – all underscoring the great mineral wealth of Sweden.

New Skilå Works

Proceeding from the Brandt Manor intersection southward on Centralvägen for 1.5 km, then turning left at the sign marked "Kopparverket/Ekomuseum" (intersection = N59.8135 E15.5573), and proceeding 700 m, takes one to the new Skilå copper works (N59.8150 E15.5697). The Ekomuseum sign greets one, "Välkommen till Kopparverket." The new works began in 1802-1807. When timber gave out in those days, one moved the smelter, and so Old Skilå moved to New Skilå.

A great deal of the original equipment still exists – pumps, towers, foundations of hearths, remnants of roasting ovens, slag heaps, and charcoal. Paintings are presented showing the process of producing high grade copper, as well as maps and drawings of equipment. The year of the local inhabitants was divided into seasonal activities: summer, plant the crops and harvest; fall, collect wood and prepare charcoal; winter, take ore to the smelting sites; spring, the smelting process is carried out (it was necessary to wait until the ice thawed so that water power would be available for pumps and hammers and washings). The assay building still exists, dating from 1819; inside the hut, huge hanging balances were used to weigh the copper ingots. One of these crude ingots – heavy! – was on exhibit in the assay building. The output of the Copperverket was about 70 tons per year.

Bispberg (Map, Figure 2)

Bispberg, the discovery site of molybdenum and tungsten, is 60 km north of Skinnskatteberg. It can be reached from Stockholm by driving northwest on freeway E18 (68 km) to Enköping, then on highway 70 (110 km) to the outskirts of Säter. Driving up highway 70 is impressive, with the beautiful Bispberg Klack with stark granite walls, 314 m high, looming in the distance. Turn right (north) at the traffic circle (N60.3380 E15.7788), and drive 3.0 km up the mountain to the Bispberg iron mine (N60.3612 E15.7925). *Caution! While driving these 3.0 km, turn right after 2 km at the intersection N60.3542 E15.7803 (Sign "Bispberg" points to right); again, after 800 m more, do not turn left at the intersection N60.3599 E15.7884 to follow Bispberggatan and the Street View route, but instead go straight, which is not on Street View.*

The Iron Mine

Beside the acre-sized flooded mine area, on a hill, stands a well-preserved Bispberg mine building, adorned with the classic Falu red paint (see Falun below), with a high tower pithead capping the "Vasa Shaft" ("Vasaschaktet"), named for King Gustav Vasa (1496-1560). The tower pithead is graced with the alchemical symbol for iron (Mars symbol, ♂) (Figure 9). A large billboard sign outside is presented in both Swedish and English. It explains how iron ore has been extracted from this area for 600 years; mining operations ceased in 1967. The mine region itself is a huge lake of water – a large pit now flooded.

Figure 9. Bispberg iron mine. A large billboard nearby in both Swedish and English explains how iron ore has been extracted from this area for 600 years; mining operations ceased in 1967. (Photograph by V. R. Marshall.)

Bispberg Klack

Farther up the road (250 m) is a parking area (N60.3614 E15.7974), whence one can hike up to the summit of the mountain (N60.3572 E15.8153), a 1.5-km exercise. The view on top is impressive, with a breathtaking panorama of the Swedish countryside. The exact location of the source of Scheele's molybdenum and tungsten ore is not known – but it would be either the iron mine or somewhere along the slopes of Bispberg Klack.

Cronstedt's Home

The location of the last home of Axel Cronstedt (discoverer of nickel) is known, in the village of Nisshytte. His mansion burned down in the 1800s and only a stone foundation remains. Today Nisshytte is an attractive rural settlement, with cottages for rent where summer vacationers can rest, hike in the forests, and swim and fish in the lakes. The location is a suburb of Säter, and can be reached by turning south at the traffic circle described above (N60.3380 E15.7788), and proceeding 8 km to N60.2832 E15.7260. In 1751 Cronstedt found a "Tungstein" (heavy-stone) at Bispberg – later named "scheelite – from which Scheele discovered the element tungsten three decades later.

Garpenberg (Map, Figure 2)

The Garpenberg Mine is the source of Scheele's fluorite which he examined at Uppsala. It can be reached from Säter by driving 16 km southeast on highway 70 to the intersection with highway 270 (N60.2841 E15.9936), driving northeast 5 km on 270 to the intersection at N60.3168 E16.0442 ("Garpenberg 10" sign), and driving east 8 km to the mine (Boliden Mines) on Garpvägen (N60.3081 E16.1782). To the right are a number of turnoffs to the huge open pit mine at N60.3091 E16.1922. There are also underground mines reaching through large reserves of copper, lead, zinc, silver, and gold. The list of mineral types collected from this mine is extensive.

Garpenberg is the oldest currently-operating mine in Sweden. Operations date from the 1400s when originally iron was the most sought-after metal.

The Garpenberg Mining chapel (Gruvkapellet) is reached by turning right on Gruvvägen (N60.3095 E16.1819); then on Kapellvägen, on to the modest Falu-red chapel (N60.3081 E16.1867). This two-story steepled chapel is reputedly the last remaining one in Sweden, dating from the early 15th century. Downstairs is a tidy sanctuary, while upstairs is a mining museum, showing old mining tools, furnishings, models of old mining constructions, and other memorabilia.

Falun (Map, Figure 2)

Falun is reached by driving 23 km northwest from Säter on highway 70, turning right on freeway E16 and proceeding 18 km further. The Falun copper mine is the source of the pyrites from which Berzelius discovered selenium. Also at Falun, Johan Gottlieb Gahn co-discovered manganese, preparing the first metallic material; and Nils Gabriel Sefström "rediscovered" vanadium.

Falun Mine

As E16 (also known as highway 50) enters Falun, turn left at the traffic circle (N60.6020 E15.6200) on Gruvgatan; the entrance to the famous Falun Mine is 250 m further (N60.6005 E15.6154); the gateway is a huge arch. The first view is a huge open-pit mine, with several buildings on the rim. In addition, one can take tours via an elevator to the interior mine, a huge cavern deep inside the earth. The buildings are all painted with Falu red ("Falu rödfärg"), prepared by mixing water, rye flour, linseed oil, and Falun iron residues containing iron oxide. A silo on the other side of the chasm, painted red, has a large alchemical symbol for copper (Venus, ♀).

Berzelius discovered selenium in pyrites from this mine, an ore used in his sulfuric acid manufactory at Gripsholm (see below). The Falun Mine is the oldest copper mine in Sweden, beginning production in the 13th century, although some preliminary copper had been processed from ores in the area dating from 800-1000 CE. The impact of the mine's contributions to the royal coffers was enormous, providing revenues for the Swedish expansionist policies of the 17th century. The mine ceased production in 1992.

Through the centuries many scientists have visited the Falun mine to study its rich supply of minerals. The mine museum has exhibits on the minerals obtained from the mine, mining procedures and equipment, and on J. G. Gahn (who had been a consultant at the mine) and his laboratory apparatus.

Copper pyrites (sulfides) are a major form of the ore. Through the millennia the pyrites have oxidized to sulfates, frequently forming white sulfate mineral deposits which could be seen during a tour of the interior mine. Leaching of the sulfates has steadily contributed to acid pollution over the years.

The Falun Mining School (Fahlu Bergskola)

The extensive activities of Falun mine gave rise to the Fahlu Bergskola, located in the village 1.2 km northeast on Gruvgatan.

Gahn's laboratory was located at the corner of Bergsskolegränd and Trotzgatan (N60.6058 E15.6352), present site of a bank building (recently converted to a restaurant) and directly across from the cozy Winn's Hotel. Gahn was a critically important asset to the Falun Mine enterprise during his tenure there during the period 1760-1818. His laboratory was essentially a blacksmith's shop, but his skill was supreme and his results were accurate. This laboratory was taken down in 1840 to make way for the school.

Sefström's laboratory was at the "modern" Fahlu Bergskola in the period 1819-1868. Sefström discovered vanadium in a magnetite found at Taberg (see below). The location of his laboratory was at Åsgatan 1 (N60.6052 E15.6350). The buildings of the school were taken down in the 1970s, much to the consternation of conservationists. The site is now is occupied by Åhléns, a chain department store found everywhere in Sweden (see above for Scheele's laboratory at an Åhléns in Uppsala).

Los (Loos) (Map, Figure 2)

Nickel was discovered in a cobalt mine in Los, a remote village 360 km north of Stockholm. It may be reached by driving 170 km north from Falun. This long stretch of roadway, highways 69 and 70, leads to Mora, interesting because of its 50-km meteorite impact crater, Europe's largest. From the road one can see some of the peripheral lakes that encircle the eroded crater resulting from the meteor strike 377 million years ago. Then the road leads via E45, 310, and 296 to Los. Los has a main north-south road (highway 296, Grubyvägen) from which the entire village is accessible.

Entering Los from the south, one is greeted by a sign, "Welcome to Loos!" with the old spelling. Sweden mandated a sweeping orthography reform in 1906 (e.g., "Upsala" to "Uppsala"), but the old spelling persists for some historical names. Many people resist the spelling change of "Loos" and one will find it on signs and even in recent modern scientific literature.

Nickel Monument

Driving north, a towering (30-m) nickel monument is immediately apparent (N61.7413 E15.1613). At the base of the monument is a resting place with benches and plaques in both Swedish and English, reading "For centuries cobolt [sic] ore was mined in the township of Los to be used in the colouring of glass and porcelain. In 1751 Axel Fredrik Cronstedt (1722-1765) discovered in the ore the new element nickel which was later to become of worldwide importance in high quality alloyed steel. Cronstedt, metallurgist and chemist, belongs to the great pioneers in the field of mineralogy. In 1758 he was the appointed mining master for the entire Swedish east-west mining region. This memorial sculpture by Olof Hellström and entitled 'Nickel Form' was erected in 1971 by the township of Los, International Nickel Limited and the Royal Swedish Academy of Sciences, to which Cronstedt was elected in 1758." Olof Bernhard Hellström (1923-) is a painter and sculptor; his works include a bronze sculpture "Liberation" in Stockholm. The nickel monument looks like nickel but is composed of stainless steel.

Loos Cobalt Mine

The Loos Koboltgruva (N61.7420 E15.1566) is quickly reached by driving ½ km north and turning left onto Pokerbacken (N61.7450 E15.1559) and driving 300 m further. The mine is open daily during summer months, and is open with appointment otherwise (arranged by telephone). Tours are available within the deep recesses of the mine. The mine was operational from 1736 to 1773 and was worked not only for cobalt but also copper and bismuth. As with any Swedish mine, there is a myriad of different minerals that may be found. With their Geiger counter, the authors noted a radioactive layer upon descending!

A spacious museum has exhibits on the history of the mine, the uses of cobalt, and the discovery of nickel. The host was most gracious and samples of cobalt- and nickel-minerals were furnished to the authors, as well as cobalt glassware.

A cobalt glassworks was established at Sophiendal, about 8 km southeast; it was operational only between 1763-1771 and today only scattered ruins remain.

Gripsholm (Mariefred) (Map, Figure 2)

Berzelius discovered selenium in sludge produced in his Gripsholm sulfuric acid plant, 55 km west of Stockholm, reached by freeway E20 or by train. In either case, turn right (automobile), or disembark (train) at Läggesta (N59.2488 E17.1678). Drive, or take the miniature train (fun!) 3 km to Mariefred, a popular tourist site on Lake Mälaren, which extends all the way to Stockholm. The narrow gauge train terminates at the boat dock (N59.2588 E17.2177); a short walk can take one to the sulfuric acid site (½ km) or to the famous Gripsholm castle (¼ km).

Sulfuric Acid Manufactory

In 1816, Berzelius and Carl Palmstedt (1785-1870), a Swedish professor and schoolmaster. invested in a sulfuric acid manufactory at Mariefred. Here pyrites were roasted (oxidized) to produce sulfuric acid – a common procedure for production of this commodity (this is how thallium was discovered simultaneously by William Crookes (1832-1919) in England and Claude-Auguste Lamy (1820-1878) in France). Noting a radish-like odor in pyrites from Falun, Berzelius was searching for tellurium in the sludge by-product. What he found, instead, was a new element, selenium (named for Selene, "the moon," analogous to tellurium for Tellus, "the earth").

The manufactory was destroyed by fire in 1825. Berzelius' experience here was not as enjoyable as his other "scientific fantasies" and he confessed he was glad to return to his "Eden" in Stockholm (*7*).

The site (N59.2563 E17.2138) is now occupied the Swedish Red Cross training grounds ("RödaKorset Idé- och utbildningscenter"), a complex of buildings, classrooms, dormitories, cafeterias, and meeting rooms (it was the left wing, "Norra Flygeln" or"North Wing," of the main Red Cross building, that originally housed the manufactory that burned down). Inside the reception center is an exhibit of "Silk Soap – Sweden's first luxury soap" which was also manufactured here in the factory of Berzelius and Palmstedt during 1820-1825. As the exhibit caption explains, "During the 19th century Sweden was a very dirty country. . . This was a new fashioned idea – a luxury soap."

Laboratory Building

The actual laboratory where Berzelius conducted his research still exists and is presently used as a tool shed. It is a small (5 m^2) hut located 100 m northwest from the Red Cross reception (N59.2567 E17.2127).

Gripsholm Castle (Gripsholms Slott)

Other than recreational activities on the lake, this is the main tourist attraction at Mariefred (N59.2559 E17.2191). This castle, dating from the 1530s, houses the Swedish national collection of portraits (over 4000). In the yard outside the Gripsholm Castle are two runestones, dating from the 11th century and using the Old Norse alphabet (Younger Futhark).The more famous of the two stones, the "Gripsholm Runestone," commemorates the Viking expedition to the Caspian region by Ingvar in 1042.

Southern Sweden

Figure 10. Sites in Southern Sweden are further from Stockholm, and may be more accessible from Malmö. Map prepared by authors.

Väversunda (Map, Figure 10)

Väversunda, 250 km west of Stockholm, is the birthplace of Berzelius. His home, and the neighboring chapel, still remain. It may be reached on freeway E4, then turning north at Ödeshög (N58.2288 E14.6705) and driving 15 km north on Mjölbyvägen to the intersection marked "Väversunda" (N58.3497 E14.7045), turning right and driving 400 m (Figure 11).

The Monument

The site is marked by a stone obelisk (N58.3468 E14.7103), raised in 1879, which reads: "År 1779 föddes här Jöns Jakob Berzelius , den Verldsbekante Vetenskapsmannen. (Here in 1779 Jöns Jakob Berzelius was born, the world-famous scientist. . . ."; this was written before the spelling reform of 1906; "world" is now spelled "världs.")

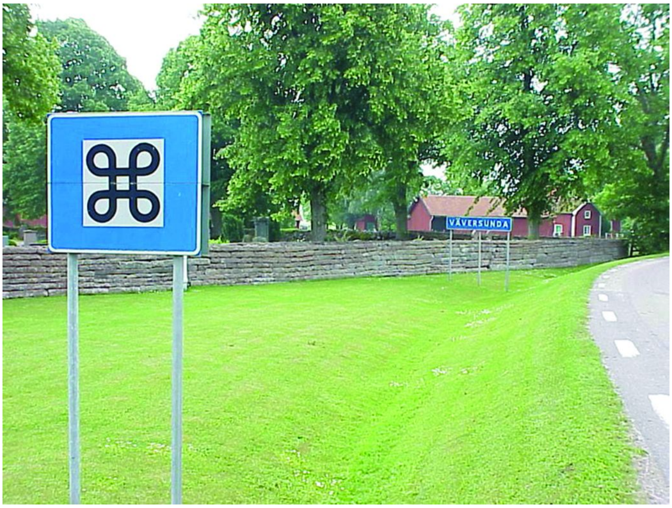

Figure 11. Entrance to Väversunda, birthplace of J. Jakob Berzelius. The cloverleaf (or Saint Hannes cross) was an ornament on Viking artifacts, and is the universal Swedish road sign for "Site of historical or touristic interest.". (Photograph by V. R. Marshall.)

The Birthplace

Beside the monument is the home where Berzelius was born. It is a plain but tidy two-story dwelling, owned by private residents and not open to the public. This is not the Berzelius home, but instead the home of Berzelius's mother, neé Sjösteen; the son Jöns Jakob was born during a family vacation. The family signpost on the walkway is inscribed with the name "Sjösten" (the authors were told by the Swedish Academy of Sciences in Stockholm that spelling was not strict in those days, and an "e" was probably omitted in order to save space). Berzelius's father, Samuel Berzelius (1743-1783), was a teacher at the Linköping Gymnasium, which Berzelius eventually attended (see immediately below).

In Berzelius's time Lake Tåkern reached up to the Sjösteen property, but has since receded and now is a field of reeds. The lake itself is a natural wildlife reserve.

The Church

Also beside the monument is the Väversunda kyrka (Väversunda church), dating from the 11th century. This structure is a fascinating blend of artistry and culture through the centuries. The church was originally wooden, but was restructured in limestone in 1160. The runic door dates to the 12th century; the vestry was fashioned in the 14th century with a fascinating blend of ancient Roman and runic styles; mural paintings of disciples and saints date from the 1600s, including a rendition of the Last Supper. The wooden pews were introduced in the 17th century, the chandelier in the early 1800s, the organ from 1896. The churchyard is surrounded by gravestones (the practice of burying relatives beside the home was abandoned about 1000).

Three generations of the Berzelius family were pastors, who attended various churches in the region. It is known that Berzelius's grandfather (Jöns Bersselius [sic], 1689-1773) was pastor at Rök and Heda (6 km south).

Linköping (Map, Figure 10)

Berzelius attended the Gymnasium in Linköping intermittently during 1793-1797; this school can be visited today. A Science Museum in Linköping includes exhibits on Berzelius. Linköping is on the freeway E4, 60 km northeast of the birthplace of Berzelius.

Gymnasium

The Linköping Gymnasium (N58.4108 E15.6183) is the Katedralskolan (cathedral school) dating from 1627 where Berzelius's father was an instructor, and where Berzelius received his secondary education. This school is located on Hastskogatan (not appearing on street maps of Linköping) which runs eastward from the north end of Läroverksgatan. The cathedral, about 800 years old, is 100 m northwest of the school (N58.4112 E15.6177). A bust of young Berzelius has been erected in front of the high school. Not only did Berzelius attend this school, but his father Samuel Berzelius was principal of this school previously. Before the gymnasium was established in 1627, the Catholic school had been in existence for almost four hundred years.

Science Museum

The Science Museum (N58.4053 E15.5888) is in "Gamla Linköping" ("Old" or "Historic" Linköping). This section of Linköping appears as it did two centuries ago. This Berzelius exhibit includes a life-size presentation of Berzelius in his laboratory (Tunnbindaregatan 6).

Taberg (Map, Figure 10)

This "magnetic mountain," near Jönköping, is the source of Sefström's vanadium (see above in Falun). This scientist showed that steel produced from Taberg ore contained a new impurity. His new element was actually a "rediscovery" of "erythronium" by Andrés del Río (1764-1849) in Mexico City thirty years earlier, who isolated it from Zimapán ore (vanadinite, $Pb_5(VO_4)_3Cl$).

To reach this interesting geological formation, drive southeast 120 km on freeway E4 from Linköping to Jönköping, and continue 10 km on E4 south of Jönköping, to the intersection (N57.6910 E14.1582), turn right (west) on Thorsviksvägen and proceed to Taberg 5 km away. As one approaches Taberg, the looming mountain appears, 140 m above the surrounding plains. As this street continues to the center of town, it passes through Bergslagsvägen (N57.6778 E14.0882) to Östra Järnsvägsgatan. The information hut is just on the right (Östra Järnvägsgatan 2, N57.6788 E14.0875), where attendants can help navigate one to the mountain base and summit.

Mountain Base

From the information booth one can travel 300 m southwest to the footbridge (N57.6765 E14.0833) which traverses 100 m to the base of the mountain and the mine entrance. Shards of magnetite have broken off and are scattered all about the ground. One can take a strong permanent magnet to demonstrate the magnetism – the entire mountain is made of magnetite, Fe_3O_4 (Figure 12). Magnetic compasses can spin wildly while one strolls through the Taberg area. Careful analysis of the ore shows titanium (<5%) and vanadium (<1%) and small amounts of olivine (ferrous silicate).

Figure 12. The entire "magic mountain" of Taberg, the source of Sefström's vanadium, is composed of magnetite, strongly attracted to a permanent magnet. (Photograph by V. R. Marshall.)

Mountain Summit

Return to Bergslagsvägen and drive north (300 m) to the intersection with Nissanvägen (N57.6803 E14.0895). Turn left and follow the winding road (and "Tabergs Topp" signs) 1.5 km to the summit (N57.6788 E14.0822). A nice view of the surrounding countryside awaits one who will take the short walk along the various nature paths. Because of the unusual mineral composition of Taberg, the area contains rare species of mosses, lichens, and ferns, and the area is environmentally protected by law. Carl Linnaeus, who was born in Råshult, Småland, 90 km away (Linne's Råshult; N56.6181 E14.2027) visited the area in 1741 and was impressed with the variety of plants, declaring the mountain "One of Småland's miracles," with "nothing like it anywhere else in Sweden to see (*8*)." A lodge beside the parking lot has an interesting exhibit inside showing the layout of the mine. A huge cavity in the middle of the mountain has been created by half a millennium of mining beginning in the Middle Ages. By the mid-1800s many blast furnaces were operated a full speed. However, by the 20th century, mining operations had ceased, resuming temporarily during World War II. Today the area is a nature preserve.

Lund (Map, Figure 10)

Christian Blomstrand performed some critical work that helped resolve the niobium/tantalum controversy, and he prepared the first pure metallic sample of niobium. Lund is in extreme south Sweden, 20 km north of Malmö, the city of entry from Denmark.

Chemistry Building

Blomstrand prepared metallic niobium in the chemistry building, which is now the history building of the University of Lund (12A Magle Stora Kyrkogata; N55.7028 E13.1987), located between Magle Stora Kyrkogata (Large Magle Church street) and Magle Lilla Kyrkogata (Little Magle Church Street).

Modern Chemistry Building

A bust of Blomstrand exists in the present chemistry building, the Kemicentrum at Getingevägen 60 (N55.7165 E13.2090).

Malmö (Map, Figure 10)

The key scientific location in Malmö is the site of Scheele's pharmacy during the period 1765-1768. This was his second pharmacy, after Göteborg.

Scheele's Pharmacy

The site of this pharmacy is the corner of Gustav Adolfs torg 10/Södra Tullgatan 1 (N55.6022 E13.0003). The name of the pharmacy was Apoteket Fläkta Örn (The Spread Eagle Apothecary). At this site, Scheele performed his first important research, where he reported that "air-borne bits of carbon were ignited from boiling saltpeter," i.e., he noticed the spontaneous ignition of charcoal with generated oxygen. This was probably the first direct observation of oxygen before his formal discovery half a decade later (see Stockholm and Uppsala above). Also at Malmö, Scheele first observed that he could generate metallic silver without the addition of phlogiston, i.e., without a reducing agent –

by heating silver carbonate to produce silver, fixed air, and vitriolic air (oxygen). Experiments such as this led to the questioning of the phlogiston theory and eventually the advent of Lavoisier's New Chemistry.

The original building is long gone – the site is now occupied by a boutique, once called "Rock 'N Blue," now "Noa Noa." Today vendors, busy with the sale of fashionable blouses, jackets, and purses, have no way to know of the scientific importance of these discoveries over 200 years ago at this location.

Lion Pharmacy

Another historical pharmacy is the Lejonet (Lion Pharmacy, established in 1571), found on Stortorget (N55.6058 E13.0015). This modern pharmacy is 400 m north and should not confused with Scheele's original workplace.

Göteborg (Gothenburg) (Map, Figure 10)

Carl Scheele's first pharmacy was in Göteborg, on the western coast of Sweden.

Statue of King Gustavus Adolphus

In 1621 Göteborg was established by King Gustavus Adolphus (Gustav Adolf II, 1594-1632). Göteborg was located at a strategically important location for Sweden's expansion in the 17th century. A towering statue of Adolphus stands by the waterway (Stora Hamnkanalen = "Big Harbor Canal") in the city's historic center, on Gustaf Adolfs Torg, by Norra Hamngatan (N57.7071 E11.9669). Stora Hamnkanalen was constructed to provide access to goods moving in and out of the bustling center of the city.

Museum

The historical museum is located on the waterway at 12 Norra Hamngatan (N57.7062 E11.9633), 200 m west of Adolphus's statue. It is located precisely where the auction and warehouse were located for the lucrative Swedish East India Company, dating from 1731. The major source of income came from importing tea, spices, china, and silk from Asia; Sweden in turn exported timber, iron, and farming and household implements.

The Pharmacy

Scheele's pharmacy was located directly across from the auction/warehouse; his neighborhood must have been a very noisy and busy one. His site was at 13 Södra Hamngatan (N57.7058 E11.9640) (named "Apotek Enhörningen," "Unicorn apothecary") – now a beauty salon, called the "Självfallet" ("Hair-wave"). The present stone buildings were erected during the 1800s; during Scheele's time a wooden house stood at this location. Scheele moved here from

Stralsund, Germany (see below) in 1757 when he was 14. He knew only German, and learned Swedish quickly. However, he continued to use German in all his laboratory notes.

Chalmers House

Directly next to the pharmacy site is the Chalmerska Huset (Chalmers House) at 11 Södra Hamngatan. A plaque there reads (in Swedish) "This building was completed in 1807 as the residence of the Director of the East India Company, William Chalmers (1748-1811)." Chalmers, of Scottish lineage, set up in 1829 the Chalmers University of Technology (Chalmers tekniska högskola), an institution still operational (2 km south, N57.6883 E11.9767).

Stralsund, Germany (Map, Figure 1 – on Main Continent)

Stralsund is the birthplace of Carl Scheele. During his time Stralsund, in extreme northern Germany on the Baltic Sea, was in Pomerania, part of Sweden.

Rathaus

Stralsund was an important administrative and defense fortress for the German territories of the Swedish kingdom. The bust of Gustav Adolf, king of Sweden, is prominently displayed in the Rathaus (Alter Markt, N54.3157 E13.0905). Underneath is the legend, both in Swedish and in German, "Gustav Adolf king of Sweden and ally of Stralsund made his entrance here on September 10 1630 and stayed here September 10-23 and October 22-November 11 1630."

Scheele Haus

Scheele's birthplace is 150 m northeast of the Rathaus; the multi-storied gabled building is of the common architectural style of the region. The building is called "Scheele Haus" (Fährstrasse 23 (N54.3165 E13.0927). A plaque on the building, both in German and English, states "The gabled house No. 23 of the late Renaissance period, named after the discoverer of oxygen, Carl Wilhelm Scheele, who was born there, had originally been built as a hall-type house in the 14th century." This building today provides offices and rooms for civic meetings. The expansive Scheele Hall is frequently filled with crowds and music during social gatherings involving dignitaries, celebrities, or officials.

Upon entry, a relief of Scheele and a plaque announcing "Geburtshaus [birthplace] des Chemikers Carl Wilhelm Scheele." On the second floor landing is a small exhibit on Scheele. A model has been made of the collection of oxygen in an animal bladder (Figure 13), and an exhibit is presented of his study on the respiration of bees. A poster announces (in German): "Trained in apothecary sciences at 15 years of age. His career in Göteborg-Stockholm-Uppsala lasted 33 years. Named to the Swedish Royal Academy of Sciences, taking over ownership of the Köping apothecary with 35 years experience. Discoverer of oxygen and chlorine. Isolated naturally occurring acids, urea, glycerol. Contributed to analytical, inorganic, and organic chemistry. Total synthesis of HCN. Photochemical effects of silver salts. Pioneer of gas chemistry."

Figure 13. One of the exhibits – producing oxygen from mercuric oxide – in the Scheele Haus in Stralsund, Germany, the birthplace of Carl Scheele. (Photograph by V. R. Marshall.)

Nikolaikirche Museum

The St. Nicholas Church, immediately to the east of the Rathaus, has an interesting exhibit on the history of the harbor area, with a large painting depicting the appearance of the area at the end of 17th century including the harbor area, with the same prominent Rathaus and Nicolaikirche discernible.

Pronunciation of "Scheele"

Residents of Stralsund pronounced "Scheele" significantly differently from the Swedes – the German "sch" was expressed with the hard sibilant sound, as in "Schule," while the Swedes used a softer fricative, such as in the German "ich." One may imagine the young Carl Scheele probably retaining his accent for years in Sweden.

Figure 14. Southwestern Finland is accessible by boat from Stockholm. Map prepared by authors.

Turku (Åbo), Finland (Map, Figure 14)

Johan Gadolin discovered yttrium in Åbo (now Turku), Finland, which during his time was Swedish territory. The yttrium was extracted from ore taken from the Ytterby Mine in Sweden (see above). Johan Gadolin, a native of Åbo, had studied under Torbern Bergman at Uppsala and written a dissertation on the analysis of iron. In addition to his native Swedish he also was fluent in Latin, German, English, French, Russian, and Finnish. He traveled extensively through western Europe and returned to Åbo in 1797.

Signs in Turku are commonly presented in both Swedish and Finnish, sometimes causing confusion with tourists trying to find their way.

Gadolin Plaques

Arriving from the boat dock in Turku, one can take a nice, relaxing 3-km stroll northeast along Linnankatu (also known as Slottsgatan) to the town center, passing the castle along the way (N60.4357 E22.2275). The famous castle's marquis announces in three languages, "Turun Linna [Finnish], Åbo Slott [Swedish], and Turku Castle." Ninety percent of the Turku inhabitants speak Finnish, and 5% speak Swedish; in other areas in southwest Finland, the primary language is Swedish. Turku dates from the 13th century, being the oldest city in Finland and once its capital. "Turku" comes from a Slavic word meaning "market place.” The city, under Swedish influence since the 13th century and part of the Swedish empire during the 17th century, was named Åbo (Swedish, “dwelling by the river”). After the Finnish War Sweden ceded Finland to Russia in 1809.

At the intersection of Aurakatu (N60.4497 E22.2680) turn right and proceed 400 m to the Gadolin plaques (N60.4467 E22.2728), on the north side of the street (which is now Kaskenkatu/Kaskisgatan).

There are two metal plaques in front of a fish restaurant (Kalaravintola Kaskenahde), mounted on a shoulder-high stone wall, one in Finnish, the other in Swedish. The one in Swedish: “PÅ DENNA PLATS I GÅRDEN 161 I KLOSTERKVARTERET HADE JOHAN GADOLIN KEMIPROFESSOR VID DEN FORNA ÅBO AKADEMI, SITT LABORATORIUM ÅREN 1797-1814.” (“On this site at the house number 161 in the Cloister Quarter the professor of chemistry at Åbo Akademi Johan Gadolin had his laboratory 1797-1814.”) The house is now an orphanage and still exists, at Luostarinkatu (Finnish) / Klostergatan (Swedish) (N60.4467 E22.2743). However, this is not where the yttrium work was done; this was done earlier in the university laboratory in 1794 (see below).

Gadolin used to cultivate a plantation south of his home. At the present time at this site is the Surutoin Restaurant (Kaskenkatu 12, N60.4448 E22.2752), which in the late 1900s served a special dish called “Vegetables from Professor Gadolin’s garden” (this information was made available to the authors by Pekka Pyykkö, the renowned Finnish chemist). At the restaurant the authors inquired, but no one inside the restaurant today – even the waitress who was studying both integral calculus and Sibelius – ever heard of Professor Gadolin.

Gadolin’s Earlier Laboratory

The laboratory where Gadolin performed his yttria research no longer exists; it was destroyed in the “Great Fire of 1827” which raced down the hill to the center of town. The laboratory was beside the cathedral (Turun tuomiokirkko), which itself was badly damaged in the fire, but was restored and is a prominent landmark (Tuomiokirkonkatu 1, N60.4525 E22.2785). Study of historic maps allows one to place the original site of the laboratory at 150 m northeast of the cathedral, at N60.4533 E22.2805 (Henrikinkatu 7/Heriksgatan 7).

The Great Fire of 1827

A plaque can be found commemorating the Great Fire, 1.0 km north of the Gadolin plaques, on Puutori (square), Aninkaisenkatu 9, on the sidewalk (N60.4553 E22.2700). The plaque is rendered in both Finnish and Swedish. The Swedish text reads: “PÅ DENNA PLATS UPPSTOD DEN 4 SEPTEMBER ÅR 1827 ÅBO BRAND I BORGARDEN HELLMANS GÅRD STADENS NORRA KVARTER No 125, 126, 127.” (“On this site on September 4th 1827 started the Great Fire of Turku at the burgher Hellmans house of the North Quarter number 125,126,127.”) Supposedly the fire originated in the bakery – commonly a dangerous source of fires with flour dust in the air which could spontaneously ignite; and with wooden houses in the villages, fires could quickly rage out of control (remember that in the "Stockholm" section, we learned that Berzelius' royal bakery was apart from the castle, by the water).

After the fire the University relocated to Helsinki. A new university was founded in Turku in 1918, the Åbo Akademi. The Chemistry Building, built in 1969, is named the Åbo Akademi Gadolina (Akatemiankatu; N60.4518 E22.2795).

Handicraft Museum

An area that escaped the fire was Luostarinmäki (Luostarin Hill), where today the Handicraft Museum (Käsityöläismuseo or Hantverksmuseet; N60.4472 E22.2768), an open air museum, may be visited. Guides in native costume describe day-to-day living just as it was in the 1800s. The theme is much like Stockholm's Skansen Park (see above), but on a reduced scale. This is found about 200 m north of the Gadolin plaques.

Vartiovuori (Observatory Hill)

Another area that escaped the Great Fire was the (old) observatory (200 m north of the Handicraft Museum), which still exists and may be visited today (N60.4487 E22.2767). The university continued here several months before moving to Helsinki. A fascinating outdoor exhibit on Vartiovuori is a series of signs that announce sea-level in years past. A sign at 50-m altitude announces that this was sea level 5000 years ago. The land is rising! The icecaps are melting, and because of geological isostasy, the continents are floating upwards.

Skogsböle, Finland (Map, Figure 14)

Anders Ekeberg found tantalum in two different sources: yttrotantalite from the Ytterby mine (see above), and tantalite, $(Fe,Mn)Ta_2O_6$, from Skogsböle, Kemiö (Kimito Island), Finland. Skogsböle (Swedish for "forest-village") is remote, but for the adventurous the drive is a beautiful rural landscape of forests, rolling hills, and rock outcroppings. From Turku take freeway 1 (25 km) to the intersection with highway 181 (N60.4249 E22.6713). Drive (36 km) to Kimito, then 7 km further to the intersection (N60.1285 E22.6379) with Lövbölevägen/Lovbölentie. Turn right and drive 4 km further. A dirt road proceeds south (left) 400 m further to the mine site (N60.1432 E22.6000).

The Mine

This is the site of an old tin mine which no longer exists. Today the area is an extensive feldspar quarry, and may not be open to the public. The original tantalite lode has been exhausted, and the area is surrounded by thick brush.

The Kimito Church (Kemiön Kirkko)

This is one of the oldest stone churches in Finland (Finnudsvägen/ Suomenkulmantie; N60.1690 E 22.7453), dating from the 14th century. This church is of scientific interest; it was referenced by Nils Gustaf Nordenskiöld (1792-1866), the mineralogist who first described tantalite in his publication of 1821, to locate the mine. He said the mine was "3/4 mile from the Kimito Church" ("drei Viertel Milen von Kimitto's Kirche"). This caused great confusion with the authors until it was realized this was referring to the Old Swedish mile (1 Old Swedish mile = 10.7 km, the distance one could walk for a prolonged period before resting).

Southern Norway

Figure 15. Oslo may be reached by train or automobile from Sweden, but scientific sites to the south must be visited by automobile. Map prepared by authors.

Knaben, Norway (Map, Figure 15)

The husband-wife team of Walter Karl Friedrich Noddack (1893-1960) and Ida Eva Tacke-Noddack discovered rhenium in Berlin, Germany. They were able to isolate 1 gram of rhenium from 660 kilograms of molybdenite (MoS_2) obtained from several of Norwegian sites. One of their more prolific sources of rhenium-bearing molybdenite is the mine at Knaben, Vest-Agder, Norway. This mine provided strategic molybdenum used in steel armament for the WWII Nazi effort and was bombed twice by the allies in 1943. Mining operations were carried on during the period 1885-1973. Tourist lodgings which are now available were once housing for mine workers.

This mine is 80 km northwest of Kristiansand, on the southern tip of Norway. At the intersection of highways 42 and 465 (N58.5235 E06.9355), turn north on 465 and proceed 21 km to the intersection at highway 839 (N58.6554 E06.9470), then 8 km further to the information board in the village of Kvinesdal (N58.6632 E07.0737). (This rural narrow road, so far, is actually traced by Street View!). At the information board, take the left fork and continue on ½ km further to the Knaben mining area (N58.6592 E07.0735; not included in Street View).

The area is popular during the ski season in the winter, but with everything covered with snow, for the mineralogist/chemist this time of the year would not be so interesting. Even during the last days of June, when the authors visited, patches of snow still remained, and the museum was not yet open.

Mining Area

Many buildings – mills, washing equipment, elevators – still remain on the slopes of the mountains. Scattered about the ground are slabs of 900 million year old Precambrian granitic gneiss, rich with molybdenite appearing as metallic solder-like splashes. The molybdenite is rich in rhenium, with concentrations as high as 7.5 ppm. (Historically, molybdenite, native lead, and graphite were all confused with one another; Scheele distinguished among the three in 1779).

The physical appearance of the Knaben molybdenite with its metallic-appearing splashes are different from that, for example, at Climax, Colorado, whose light-colored ore has microscopic inclusions of the dark molybdenite that cannot be seen with the naked eye.

Mine Museum (Knaben Gruvemuseum)

A museum in the old administration building ("Kontoret"; N58.6614 E07.0744) presents information about mining methods, and the history of the mine including the German occupation during World War II. (Note: the museum is only open during the month of July.)

Evje, Norway (Map, Figure 15)

Another rich source of rare earth minerals (including euxenite) is Evje Mineralisti "Mineral Path," a group of interesting mines, at Evje, Norway. In fact, the first specific scandium mineral was discovered here, thortveitite $(Sc,Y)_2Si_2O_7$), at the Flåt nickel mine. Evje is 50 km north of Kristiansand. Evje Mineralisti is a pegmatite area 2 km east of Evje. Drive north on highway 9, turn right onto 306 at the intersection (N58.5992 E07.8295).

Sites to visit at Evje Mineralisti

The Flåt nickel mine at N58.5985 E07.8698.

The feldspar mine at N58.6022 E07.8565.
The mineral trailheads, with parking at N58.5980 E07.8555

Karlshus, Norway (Map, Figure 15)

Cleveite, the source of helium discovered by Per Cleve and William Ramsay, is from Karlshus, which is 70 km south of Oslo on freeway 6. A number of pegmatite dikes in this rolling countryside are exposed (small mines, road cuts, and quarries, e.g., N59.3475 E10.8742) from which cleveite was taken, as well as broggerite, a thorium-rich uraninite. These minerals were also important in the first determination of the age of the earth by studying their radioactivity. The original Karlshus mine (also known as the Råde, or Halvorsrød, Mine) was located in farmland, now behind an elementary school house complex (Idrettsveien 30; N59.3602 E10.8647).

Kragerø, Norway (Map, Figure 15)

Hafnium was discovered by György de Hevesy (1885-1966) and Dirk Coster (1889-1950) in alvite (a form of zircon, $ZrSiO_4$) in Copenhagen, Denmark. They discovered alvite was particularly rich in this new element in the zirconium family. The specimen they analyzed was from Kragerø, in the southeastern part of Norway. Also present in Kragerø, as well as Evje, Norway (see above), was euxenite, $(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$, from which Lars Nilson discovered scandium.

It is known that the alvite that Hevesy and Coster studied specifically came from the Tangen Mine near Kragerø. This mine is relatively inaccessible, but if one is interested in a unique mine with a different assemblage of minerals, it might be worth one's while. On Kalstadveien (the main east-west street in Kragerø), proceed to the intersection of Kalstadveien and Dalaneveien (N58.8715 E09.3757). Drive westward 200 m to the intersection with Haugstranda, a dirt road (N58.8707 E09.3714). Park and walk 1.0 km along the dirt road and then left 100 m through thick brush and over steep rocky ground to the mine (N58.8715 E09.3540).

The Mine

The Tangen Mine is a huge cavern. It is a Precambrian pegmatite formation, which once furnished a great deal of feldspar and quartz for the porcelain industry. Specimens of alvite were easily found, i.e., hafnium-rich zircon. Tangen Mine is also known for its bluish albite ($NaAlSi_3O_8$, not to be confused with alvite) and schorl (a black form of tourmaline, $NaFe_3Al_6(OH)_4(BO_3)_3Si_6O_{18}$) – and many specimens of these were found in the mine as well. Lanthanide minerals also are found here, but specimens are rare and difficult to find. Around the time of World War I, dynamite was used to blast out material, in time for the 1923 discovery of hafnium.

Løvøya, Norway (Map, Figure 15)

This island in southeast Norway is the source of the thorite from which Berzelius discovered the element thorium. This island is reached by taking a small boat (Figure 16) from the town of Brevik, 16 km south of Skien (the home of the author and playwright Henrik Johan Ibsen, 1828-1906). The mineral thorite itself was discovered by a local pastor known as Hans Morten Thrane Esmark (1801-1882), while he was hunting ducks.

Figure 16. Docking by the Thorihullet ("thorium hole") on the small island of Løvøya in a Norwegian fjord. Thorium was originally discovered here by a parson hunting water fowl for the dinner table. The thorium has long been depleted, but upon close inspection one can find small (fingernail-sized) dark nodules of of zircon, magnetite, molybdenite, and other minerals in the white pegmatite. (Photograph by J. L. Marshall.)

The Island of Løvøya

Løvøya is an island in the fjord (Langesundsfjorden) located 2.5 km east of Brevik. It runs northeast-southwest, measuring 1.2 km long and 200 m wide. Løvøya cannot be seen from Brevik; it is on the other side of a larger island, Sandøya. Løvøya, like the other islands in the fjord, is covered with brush and trees. In Norwegian, "øya" means "island." "Løvøya means "leafy island."

While crossing the fjord, we could see the horizon and view many geological ages. To one side of the fjord an Ordovician limestone quarry lay, marked by a smokestack of an accompanying cement factory; to the other side loomed a cliff of Permian blue syenite (used as a building material for buildings).

The thorite ($ThSiO_4$) crystals were originally collected from two outcroppings – Permian pegmatites – on the west side, called "Thorite hole 1" and "Thorite hole 2" (N59.0574 E09.7350 and N59.0560.36 E09.7394, respectively).

Thorium oxide was found to be an excellent refractory. After the invention of Welsbach's lamp (a precursor of the Coleman lantern), where thorium oxide was used in the mantles, thorium was in great demand. With the thorite run of 1895-

1896 on Løvøya, the supply was depleted from this site. When the authors visited, the main minerals observed were zircon ($ZrSiO_4$), magnetite (Fe_3O_4), aegirine ($NaFeSi_2O_6$), and molybdenite (MoS_2).

The Island of Låven

Another small island in the Langesundsfjorden is 8 km to the southeast (N58.9954 E09.8174), known as Låven, meaning "the barn" for its shape. It measures only 30 by 60 m. Its importance is "mosandrite," which was originally discovered on this tiny island (see Mosander above under Stockholm). Mosandrite is a hard black mineral with the formula $(Ca,Ce,RE)Ti(SiO_4)_2F$.

This tiny island is protected by the government and minerals cannot be collected. A marker – "Låven Naturminne " ("Nature Memorial") – is mounted on the island, informing one that this is a conservation area because of the historical significance of its minerals. Hans Morten Thrane Esmark, who discovered thorite on Løvøya 8 km northwest (see text), was the first to notice the significance of the mineral treasures here.

The Brevik Museum

The Bymuseum (City Museum) at Brevik is located at 4 Kirkevegen (N59.0531 E09.7014), on the island of Sylerøya and can be reached by automobile. Inside the museum is a portrait of Hans Morten Thrane Esmark, the discoverer of thorite. He spotted the mineral as it glinted in the light as he was passing by in his boat. Hans Esmark was not only a parson of the Brevik church on Sylerøya, but also a geologist, chemist, biologist, and inventor. He was the only amateur who has been granted honorary fellowship in the Mineralogical Society of England. He was also the first mayor of Brevik.

Hans showed his new mineral to his father, Jens Esmark, the first geological professor of the University of Christiana (Oslo). The father sent it to Berzelius, who found the new element. Esmark wanted to name the mineral "berzelianite," honoring the person who performed the analysis, but Berzelius refused, naming the element after the Norse God of thunder, Thor.

Kongsberg, Norway (Map, Figure 15)

The father Jens Esmark (1763-1839) was originally from Denmark. Before Oslo, he was professor at the Kongsberg Mining Academy (Kongelige Norske Bergseminarium). Kongsberg is 75 km southwest of Oslo, and can be reached on freeway 18, then highway 134.

The Museum

The Norsk Bergverksmuseum (Nordic Mining Museum; Hyttegata 3 = N59.6662 E09.6495) features the history of silver mining in the area. Norwegian uses the "crossed hammers" of eastern European culture. One never sees these in Sweden, whose mining industry was independently developed; in Norway, however, German mining technology was imported. The Norwegian name for "crossed hammers" is "hammer og bergsjern."

Silver coins, dating from the 1600s are displayed – ½ speciedolar and 1 speciedolar. The "Kingdom of Denmark" is sometimes used to describe the political union between Norway and Denmark during the period 1536-1814, when the rigsdaler circulated freely between the two countries. These coins were analogous to the Swedish riksdaler. All were named after the German "Thaler" (or "Reichsthaler"), named after the "Joachimsthaler" from Joachimsthal in Bohemia (now Jáchymov in the Czech Republic).

Christian IV (1577-1648) was king of Denmark and Norway 1588-1648 and is featured on coins displayed in the museum. Christiansand in southern Norway, the port from which one travels to England or destinations in the Baltic, was named after him. Norway's capital, Oslo, was once called Christiania in his honor. He founded Kongsberg in 1624, originally Konings Bierg, as a mining community to exploit the huge silver deposit there. In the mid-1700s Kongsberg was the second-largest city in Norway.

The Academy

The Old Academy building also still exists (Kirketorget 3 = N59.6658 E09.6453), with plaques that describe the history. The Mining Academy was founded in 1757; when the University of Christiania [Oslo] was created in 1813, Jens Esmark moved on to that university. He successfully explained ancient glaciation in Norway and explained how fjords in Norway were created by glaciation. In 1825 he was elected a member of the Swedish Royal Academy of Sciences.

Conclusion

"Sweden contributed lavishly to eighteenth-century chemistry (*9*)." — So states the famous historian Will Durant, who has created for us a broad portrait of the panorama of civilization. With its explosion of discoveries, epitomized by Carl Scheele, Northern Scandinavia showed it was truly on the forefront of the Scientific Enlightenment. This reputation continued through the 19th and 20th centuries, culminating in the legacy of Alfred Nobel. Italy had its Galileo, Great Britain its Industrial Revolution, the Holy Roman Empire its Stahl and phlogiston, and France its Lavoisier and the New Chemistry, but Sweden and environs had their unique place with their torrent of scientific activity, as exemplified by the impressive list of Table I. Northern Scandinavia holds something special for the Scientific Tourist, who may find it to be a rich source of education and entertainment.

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Chapter 12

The Auer von Welsbach Museum

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Carl Auer von Welsbach (1858−1929) was a brilliant scientist and inventor who revolutionized the use of light and fire, making our lives considerably easier. A museum dedicated to his life and works was opened in 1998 in Althofen, Carinthia, Austria. The museum exhibits the inventions that sparked the growth of the gas industry and the electric industry.

Introduction

The Auer von Welsbach Museum (*1*) is located near the prominent parish church of Saint Thomas in the Old Town of Althofen (N: 46.8742 | E: 14.4739), Carinthia, Austria (Figures 1 and 2).

Figure 1. The Old City of Althofen is considered the oldest inhabited hilltop settlement in Austria. Photograph: Roland Adunka.

Figure 2. The Auer von Welsbach Museum, Old City of Althofen. Photograph: Roland Adunka.

Dr. Carl Auer von Welsbach (Figure 3) was born in Vienna on 1 September 1858 and died in Welsbach Castle, Carinthia, on 4 August 1929. He is considered Austria's most outstanding chemist: an inventor, discoverer, and successful entrepreneur who was nominated many times for the Nobel Prize. He founded new branches of industry as well as numerous companies in Austria, Germany, France, England, Canada and the United States.

Auer first studied in Vienna before continuing his studies in physical chemistry at the University of Heidelberg under the direction of Robert Wilhelm Bunsen (1811−1899). After returning to Vienna he discovered the rare earth elements praseodymium and neodymium in 1885 by successfully splitting *didymium*, which was once thought to be a single element. Neodymium is presently the most important of the rare earth elements. It is the strongest permanent magnet material and is irreplaceable in electric drive technology and generator applications. Today, these magnets are being successfully used in the smallest motors in toys and cameras as well as in electrically powered bicycles, hybrid automobiles, and in wind turbines.

Figure 3. Dr. Carl Auer von Welsbach. Painting by the Viennese artist Prof. Andreas Patzelt. Courtesy: Archive of the Auer von Welsbach Museum.

Inventions

In the 19th century, the Bunsen burner flame and the gas mantle were responsible for the rapid increase in gas consumption and the growth of the gas industry. In Vienna in 1885 Auer, then 27 years old, invented the revolutionary "Welsbach mantle" by experimenting with rare earth oxides. Numerous lighting engineers had tried, with little success, to improve the luminosity of gas lighting using different types of burners.

Auer von Welsbach's gas mantle was the first artificial light source using the sootless, non-luminous Bunsen burner flame. The mantle was used over the flame and it incandesced with a brilliant light. The benefits for the gas industry and Auer's resulting economic success were enormous. Never before had an invention spread so quickly throughout the world as the *Auerlicht* ("Welsbach light"). Operating rooms, factory buildings, apartment flats and streets in many cities were illuminated by the *Auerlicht*.

The key advantage of the gas mantle was that most towns and cities had already installed a gas pipe network for the purpose of gas lighting. Since the *Auerlicht*'s running costs were only a sixth of the sooty gas flame previously used, conversion to this new energy-saving lamp was rapid and universal.

The *Auerlicht* gas mantle is simple in design and principle. It consists of a fiber webbing soaked in a salt solution of thorium and cerium (today yttrium-cerium). When lighted for the first time, the webbing burns away and leaves a skeleton of oxide ash. Placed over a Bunsen burner flame, this gas mantle emits a light more brilliant than any available theretofore.

The invention of the *Auerlicht* rendered the sooty gas flames unnecessary. Therefore, around the year 1900 gigantic gas tanks were built such as the well known Gasometer gas tanks in Vienna (*2*). The purified gas could now also be used for cooking and heating and thus gas consumption increased rapidly. Soon afterward, our talented inventor also occupied himself with electric light technology in order to improve Thomas Edison's (1847−1931) carbon filament lamp that he had been producing from 1879 onward. Auer invented a powder metallurgy process for the production of wires made of osmium. In 1898 he received a patent for the first practical metal filament lamp. In the same year Auer founded Treibacher Industrie AG, in full operation to this day, and in 1906 he founded OSRAM (presently Osram/Sylvania).

To generate power for his metal filament lamps, four power plants were built between 1898 and 1929. After it was expanded, the most recent plant eventually became the largest power plant in Austria.

In 1903, Auer von Welsbach invented ferrocerium, commonly called lighter flint. When scratched, it produces a large spark which then ignites the fuel of our common cigarette lighters. It consists of an alloy of the rare earth metal cerium and iron (30%). These lighter flints are still being produced in the same factory that he founded in Treibach (TIAG). They are sold under the brand name "Original Auermetall" and account for a significant share of the world's demand for lighter flints (current annual production worldwide is approximately 10 billion units). Figure 4.

Figure 4. Three major inventions: The Gasglühlicht was the first energy saving lamp and consumed 85% less gas. The metal filament lamp with an osmium filament consumed 60% less electricity than the Edison carbon filament lamp. The Auermetall flint for lighters marked a turning point in the generation of fire. Photograph: Roland Adunka.

Discoveries

In 1905, the tireless researcher discovered yet again two rare earth elements, ytterbium and lutetium, bringing to four the total number of elements discovered, the greatest number by a single individual, although this claim has been disputed and the priority assigned to others (*3*).

However, Auer von Welsbach was a successful pioneer even outside the laboratory. He did the earliest surviving audio recordings in Austria dating from 1900. In 1908, Auer also became the first color photographer in Austria.

As Austria's most important and well-known inventor and discoverer, Auer received more recognition than any other chemist. He appeared on a 20 Schilling banknote, a 25 Schilling silver coin, various stamps and most recently also on a 25 Euro silver-niobium coin (Figure 5).

There seemed to be no end to Auer von Welsbach's versatility and genius. A recent paper suggests that he may also inadvertently have discovered neutron activation (*4*). The story goes that when Auer stored some radio-inactive materials in the presence of ^{230}Th, an α-emitter, they subsequently exhibited an unexpected radioactivity. Possible retrospective surmises are that there may have been some beryllium impurity present in the thorium sample that, when bombarded by α-particles reacted as follows: ^{9}Be(α,n)^{12}C, thus providing the free neutrons necessary for activation. This hypothesis faces some challenges: what are the substances that could possibly have been contaminants, and what are the energy requirements for the hypothetical nuclear reaction? Experimental work on this topic is presently ongoing. If a plausible scenario can be developed, it would show that Auer actually anticipated the artificial production of radionuclides, an accomplishment for which the Joliot-Curies received the Nobel Prize, by several decades.

Figure 5. Auer von Welsbach is honored on a 2012 Austrian stamp featuring his Gasglühlicht.

The Museum

Carl Auer von Welsbach's efforts to facilitate people's lives were acknowledged in many ways. The Emperor, Franz Joseph gave him the title Freiherr (a title of nobility similar to baron); he was awarded five honorary doctorates as well as the Werner von Siemens Ring; he was made Honorary Senator of the University of Heidelberg; several monuments, parks and streets were named in his honor and many other forms of recognition testify to his enduring legacy.

In its 6 rooms, the Carl Auer von Welsbach Museum displays the historic inventions and discoveries as well as other amazing achievements of this famous scientist, who was also a successful entrepreneur and generous philanthropist (*5*). The first room is dedicated to personal memorabilia and honors received by Auer von Welsbach, including his coat-of-arms bearing his motto: *Plus lucis* (more light).The second room contains original apparatus and slides related to his discovery of four rare-earth elements, as well as accolades and documents from other famous scientists. The third room recounts the history of illumination technology through the ages, leading up to Auer's inventions that surpassed all other inventions up to that time. Visitors will be enthralled by exhibitions of the earliest gas mantles and the first metallic filament light bulbs. The museum is also proud of its remarkable collection of lighters, found in room 4. The display traces the history of the lighter beginning with the first generation of fire by friction to the fancy and manifold forms of lighters used today, showing how their design has changed according to the fashion of the time. Room 5 is a small theatre showing a 4-minute video about the Treibacher Industrie AG giving an insight into the firm's large offering of products and tracing its impressive growth from its founding in 1898. The final room, 6, replicates Auer von Welsbach's laboratory furnished with the original equipment he used during his 50-years of research and innovation. It simulates the basement room in Vienna that Auer rented from Prof. Adolf Lieben (1836−1914) to carry on his work. Although the captions in the museum are in German, there is a lengthy museum guide available in a variety of languages (Figure 6).

Walking or driving from the museum, within minutes you can traverse the historic Old Town of Althofen, which is situated majestically on a hilltop with a spectacular view of the mountain range Karawanken, the natural border with Slovenia. Medieval castles, historic industrial sites, and elegant Renaissance and Baroque buildings in the vicinity (Figure 7) bear witness to thousands of years of cultural and economic activity, in particular the iron industry (*Ferrum Noricum*) that originated 2,500 years ago in Celtic times. Among these sights are Burg Hochosterwitz, a perfectly preserved 16th century fortification built upon a much earlier site and considered to be one of Austria's most impressive medieval castles, and the High Ovens (blast furnaces) of Heft, shut down in the early 20th century because of poorer ore deposits, making iron smelting economically not feasible. These and other relics of a bygone age make for interesting visits.

Figure 6. Laboratory of Auer von Welsbach reconstructed from his estate with his original laboratory equipment. Photograph: Roland Adunka.

Figure 7. Burg Hochosterwitz (left) and the High Ovens of Heft (right). Photographs: Roland Adunka.

Althofen is 290 km from Vienna and can be reached by train from Vienna or Klagenfurt (*6*).

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Chapter 13

Scientific Wanderings in Southern Germany and Austria

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This chapter explores the scientifically unique contributions to the culture, economy and history of Southern Austria and Bavaria. Salt is the unifying focus in the first part, centered on three major salt production areas that surround Salzburg and that have made a significant contribution to this city's political and economic development. The Austrian alpine village of Althofen above the Gurk River Valley is the focal point for the history of Austria's southernmost province, Carinthia. Iron, mined here from prehistoric times, and rare-earth elements, a relatively recent development on the mining scene, comprise the scientific background of this part of the chapter. Relics of ancient Roman, Celtic, and medieval cultures punctuate the landscape, making this one of the most enriching historic areas of the Austrian Alps.

In Science History: A Traveler's Guide; Orna;

When asked to describe my mental picture of a trip into Bavarian Germany and southern Austria, I first think of the amazing views of mountains and meadows, snow and raging Alpine streams; of friendly people and marvelous meals; and of salt, iron, and rare earth metals. Salt, iron, and rare earth metals - yes! They represent my scientific memories of this wonderful part of Europe.

Salzburg and Salt

Our journey begins in Salzburg, Austria, roughly an hour and a half (144 km, 89 mi) east of Munich and just a few kilometers from the German border. Salzburg, meaning "salt fort" or "salt castle," is located on the Salzach River at the northern boundary of the Alps. From the early Celtic era, it's easily defendable location made it ideal as a political and commercial center. Salt plays a central role in the history and development of Salzburg, but the history of salt itself is far longer.

The earliest records of salt usage go back to ancient Egypt, and in fact to the Wadi Natrun which is rich in sodium salt deposits, primarily the carbonate, which has the common name natron. It is easy to see the derivation of the chemical symbol for sodium, Na, from the Arabic *natrun* and the Latin *natrium*. Natron found many uses in the ancient world largely because of its desiccating properties: it was widely used for mummification and for preserving meat and fish. The more common sodium chloride became the desiccant of choice worldwide and was much sought after in the ancient world. In addition, salt is essential to the diet of herbivores and therefore essential to farmers who raise domestic animals. When meat or fish is immersed in salt, the salt gradually removes the water from the organic material by the process of osmosis, thus killing the bacteria liable to cause the foodstuff to rot. Food can be preserved for long periods of time when salted, and therefore salted food can be transported long distances without fear of spoilage. Before the advent of refrigeration and other food preservation methods, salt was the only available choice.

Salt deposits can be found in many parts of the world either in solid form such as salt domes that can be mined as a solid, as brine wells that can be pumped out, or as shallow sea beds that can evaporate to produce a solid. The salt is seldom pure – it consists of several sodium compounds as well as small fractions of potassium, calcium and magnesium compounds. Salt mining is a major industry because presently salt is one of the most important raw materials in manufacturing plastics, paper, soap, synthetic rubber and many other products. These latter day uses of salt are a far cry from dietary supplement and food preservative, and could only come about through our understanding of the nature of salt through chemistry (*1*).

The value of salt to the growth of what would become Salzburg began with the appointment by Theodo of Bavaria (c. 625-716) of Rupert as bishop in 700 CE. Rupert (660?-710) established his bishopric there and began to subject all commercial river barges to a toll. Transportation of salt from the mines south and east of Salzburg was a major portion of this commerce. These tolls supported the growth of the bishop's influence primarily to the south and east. The church/state relationship continued into the late 14th century when Salzburg gained independence from Bavaria to the west and became a part of the Holy

Roman Empire. Salzburg was then annexed into the Austrian Empire, beginning a series of annexations and re-annexations right up until its absorption in the Third Reich in the 20th century. It is presently the capital of the Austrian State of Salzburg. As a UNESCO World Heritage Site, Old Town Salzburg has many locations of historical interest. Since it is the birthplace of its most famous resident, Wolfgang Amadeus Mozart (1756-91), music and music festivals abound in the city.

Paracelsus

Another Salzburg resident, though only for a few months, left his impact on the city. Paracelsus is a familiar Renaissance scientist whom you may not associate with Salzburg. He was born Theophrastus Philippus Aureolus Bombastus von Hohenheim in1493 in Switzerland, the son of a well-known physician who fostered his early interest in medicine. He continued his studies in Switzerland, Austria, Germany, France and Italy; finally completing his degree in medicine at the University of Vienna. But his quest for knowledge continued until he obtained his doctorate from the University of Ferrara. That is where he changed his name, assuming the Latin "Paracelsus," meaning "next to or greater than Celsus," a 1st century medical writer whom he greatly admired. Paracelsus continued to travel throughout Europe and on to India, Tibet, Egypt, and the Holy Land, all the while studying different cultures and their alternative healing methods. He was at various times an alchemist, physician, botanist, miner, astrologer, and often considered a "magician" because of his medical successes.

Paracelsus pioneered the use of chemicals and minerals in medicine, and as such he is recognized as the father of toxicology. In his travels he developed a broad following and became an expert in diagnosis and treatment. Among other things, he is recognized for naming the element zink, we know as zinc, based on the sharp pointed appearance of its crystals after smelting and the old German word *zinke* for pointed. Twice exiled for practices that worked but were "offensive" to the medical field of his day, in 1541, Paracelsus finally settled in Salzburg on the invitation and protection of the Prince Palatine, Ernst of Bavaria. A plaque marks his home at Linzergasse #3 in Old Town Salzburg. Unfortunately he died shortly afterwards and was buried at his request in the cemetery at the church of St. Sebastian in Salzburg. The actual cause of his death remains unknown. Both his home and burial site (Figure 1) can be visited during a pleasant walk on both sides of the river in Old Town Salzburg (*2*).

Salzburg is also the central site for the story of the "Sound of Music," so one can spend many days engaging in activities centered on Salzburg. But back to a focus on the story of Salzburg and salt.

Exploring the story of salt involves both isolation of the salt itself and its production into a commercial commodity. There are three major areas of salt production and processing. Each can be an enjoyable day trip from Salzburg. And each will introduce you to a different story of people, salt production, history and culture (Figure 2).

The first area (and the one most commonly visited by American tourists) is only an hour away using local roads to the southwest of Salzburg. Located on the western side of the Obersalzberg mountain range in Germany's southeastern corner is the Salt Mine at Berchtesgaden and its related production site in Bad Reichenhall. The second is the Obersteinberg or Dürrnberg mine on the eastern side of the same mountain system at Hallein in Austria. An interesting note is that these two mines actually cross the German-Austrian boundaries and mine the same salt veins. The third salt center is to the east of Salzburg at Hallstatt, located on the national road linking Salzburg and Graz. The history of Hallstatt involves both salt and iron, but I will focus on the salt. Its production site is to the northeast in Ebensee. Salt brine was transported from Hallsatt to Ebensee when they were connected by the first brine-pipeline in the late 1500's.

Figure 1. Paracelsus Tomb. Cemetery of the Church of Saint Sebastian, Salzburg. Photograph courtesy of David Hart.

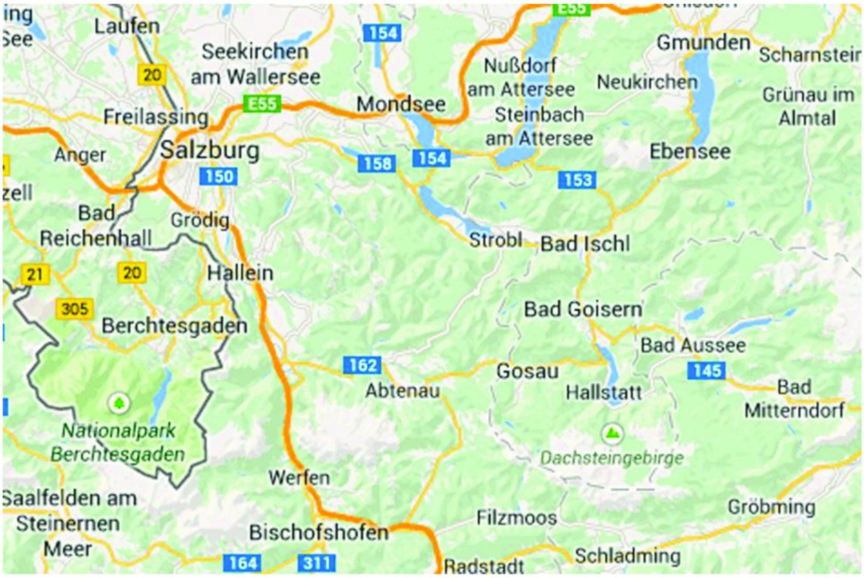

Figure 2. Salzburg and Environs. To the southwest lie Bad Reichenhall and Berchtesgaden; almost due south lies Hallein; to the southeast lies Hallstatt, and due east lies Ebensee. Map data @2014GeoBasis -DE/BKG (@2009 Google).

Berchtesgaden

Berchtesgaden is a lovely Bavarian alpine village situated on both sides of the raging Berchtesgadener Ache river. On my first visit, I lodged at the Berchtesgaden Hof, built by the French in the 1920's as a resort hotel but later taken over by the Nazis as an officer's barrack.

The mountainside east of town was also chosen as the site of Hitler's famous retreat "The Eagles Nest." Taking a half day to walk the village of Berchtesgaden and going on the Eagles Nest tour is recommended for anyone with an interest in German World War II history (*3*).

The Berchtesgaden salt mine is located on the east side of the river and north of the main village area just off the highway between Berchtesgaden and Salzburg (N47.6339 E 13.0077). The salt veins of the mines of Berchtesgaden and Hallein are both part of the "haselgebirge" formation of the Northern Calcareous Alps. These layers contain an average of 60% soluble salt separated by non-soluble clay layers (*4*). To reach the salt layers, miners first drilled into the mountain at river level and then down to a salt-containing layer. Salt was eventually mined from the deeper layers by pumping water in so the salt would dissolve to form brine. As each vein was exhausted, the miners went down to the next salt-containing vein and repeated the dissolving process. The saturated brine (approximately 26% salt by weight) was then pumped out and sent to the salt works for processing. The Salt Mine at Berchtesgaden has been in uninterrupted operation since 1517. Thus, over the centuries, mining has gone deeper into the mountains and below the level of the river bed. Current mining is mainly 300 m (1000 ft) below the original mine entry (*5*).

Up until the early 1500's, the salt was obtained by evaporation of brine near the mine entrance. When the amount of wood in the local forest decreased, the next step was to concentrate the brine on site then to float the more concentrated brine down closer to Salzburg for commercial preparation. Starting in 1816, the brine was pumped over a slight mountain pass to Bad Reichenhall for processing.

Getting workers to and from the river entry to the work level is one of the unique aspects of this mine as the salt layers became deeper. During a tour of the mine today, you essentially follow the path of the late 1800's workers. First you get on your work clothes by pulling on white canvas overalls with a leather apron worn in back. The work clothes keep you comfortable because the average temperature underground is +12 °C (56 °F). Then you climb on the train for your ride into the mine. You sit close together straddling a center bench that extends the length of each rail car (Figure 3). Then you must reach the lower work level. One way is to walk down a staircase. The traditional, and fun, way is to sit in a group of two or three and slide down a 34 m (115 ft) long bench size banister to the next level. The purpose of the leather apron is to protect you from friction as you slide down. You stop with a slight upgrade at the end. A second 40 m (130 ft) slide takes you to the lowest work level that is open for visitors.

Figure 3. "Miners" about to descend on a train into the Berchtesgaden salt mine. Photograph courtesy of Janan M. Hayes.

As you tour this level you get introduced to the entire process. You are pulled across a large salt lake on a raft. As you walk through the mine you see the different formations that have been mined. You also see some of the rooms that have been carved out for worker activities including a chapel.

Going back to the main level can be accomplished by climbing the stairs or by riding a funicular. Then you have the reverse mine train ride to the mine entrance where the changing area, museum, gift shop and food areas are located. Among the fascinating things in the museum are the actual pumps that were used in the mine and other old equipment. In addition there are many samples of the various salt crystals (*6*).

Each time I have taken the trip, I have been more thrilled and enlightened with the wonder of the science and engineering that have developed this most efficient mining system.

Bad Reichenhall

From early times (about 450 BCE) the area around Reichenhall was identified as a source of salt obtained by evaporation of local brine pools. By 1816, Georg von Reichenbach (1771-1826) had developed brine engines or pumps for transport of salt brines. Then King Maximilian I Joseph of Bavaria (1756-1825) commissioned the use of these pumps for the pipeline between Berchtesgaden and Bad Reichenhall. By December 1817, the first brine engine was transporting brine through wooden pipes the 20 km (12 mi) from the Berchtesgaden mine to processing in Bad Reichenhall. This utilized 14-ton bronze pumps to bring the brine uphill 356 m (1200 ft) for free flow down the pipeline to the processing site. The brine was piped continuously until 1927.

Since 1890, Reichenhall has been called “Bad Reichenhall” as an acknowledgement of its continuing development into a spa and famous health resort. For our interest in the salt process, the destination in town will be “Alte Saline” the museum and reconstruction of processing facilities in Bad Reichenhall (Figure 4).

Figure 4. “Die Alte Saline” at Bad Reichenhall. Photograph courtesy of Terry Eyrich.

The tour begins by watching and hearing the operation of the massive pumps. It is amazing to stand as two huge (190 m, 25 ft) water wheels turn causing horizontal and vertical movement of rods operate the smaller pumps that result in the transport of the brine throughout the refinery (Figure 5).

Figure 5. Massive pump wheels at "Die Alte Saline.". Photograph courtesy of Terry Eyrich.

As you walk through the processing area you go down narrow stairways and walk crooked little corridors to view the unique arrangement of brass pipelines, valves and pumps that have transported brine for almost two centuries from brine pools or storage ponds to processing areas. The water is evaporated by heating the brine and the resulting salt is dried in centrifuges. All processes are powered by the water pumped by the Bad Reichenhall wheels. A difference between the Bad Reichenhall brine and that coming from Berchtesgaden is that fresh water is pumped into the Berchtesgaden mine and the resulting brine is then processed. In Bad Reichenhall, the brine is obtained by drilling into the underground reserves and pumping the brine directly to the refinery.

Bad Reichenhaller salt dominates the salt market in Germany, processing 300,000 cubic meters of brine each year. The company has nearly two dozen products, including a variety of specialty salts, such as potato salt, and a selection of salts and herbs sold in their own jars. The company is also a major supplier to cheese and cured-meat producers, and its coarse pretzel salt is popular among bakeries.

The museum has displays and video presentations that expand the understanding of the variety of salt containing products containing Bad Reichenhaller salt. Samples are available and for sale in the gift shop. But each person on the tour leaves with a small shaker of the Bad Reichenhaller salt (*7*).

Hallein

The Hallein Salt Mine or Salzbergwerk Dürrnberg is located due east of the Salt Mine of Berchtesgaden with mine tunnels going west so that they actually overlap the tunnels operated by Berchtesgaden. To get there from Berchtesgaden or Bad Reichenhall, you must drive north almost to Salzburg before going east and finally south on the east side of the Obersalzberg/Dürrnberg plateau to the town of Hallein (N47.6824 E13.1004). The mine itself is located a short distance to the west and above the town.

The salt was initially mined by Celtic tribes by hand extraction of the rock salt crystals. To increase the volume of salt produced, the caves were flooded with fresh water. After a time, the salt brine would be pumped out for processing in Hallein. Over time a problem developed. The Bavarians realized that they were mining east into what was Austria and Austrians were mining west into Bavaria. The two mines actually crossed paths vertically but did not actually intersect since they were at different depths. The conflict of who owned the salt (Bavaria or Austria) was settled by treaty in 1829. The agreement settled the various conflicts by allowing each side to penetrate the border by one kilometer, by allowing the Bavarians to use Austrian forests for their brine-processing wood, and by providing for a certain number of Bavarian workers to be hired in the Austrian mine. Salt from the mine was processed downhill from the mine in Hallein and the salt product was then transported by river to Salzburg and beyond (*8*).

In the late 1600's, special guests were invited by the various archbishops of Salzburg to tour the Hallein mines. Because the town of Hallein was not as picturesque as Berchtesgaden, Hallein did not focus on tourism very much until the 1980s. Today, there is a mine tour, with a train and slide system similar to that on the German side. However, the mine tour is not quite as commercialized, but the town itself has developed more tourist activities. Commercial tours to both the Berchtesgaden and Hallein areas are available from Salzburg. Individual touring to each is also easily arranged.

Hallstatt

The third salt-related expedition out of Salzburg focuses on the production at the Hallstatt mine (N47.5622 E13.6493) and the Ebensee (N47.8071E13.7790) processing area southeast of Salzburg. This area is off the main highway (E55, E60) from Salzburg to Graz on the northern end of the Austrian Alps. It is in a beautiful area of lakes, mountains and is a great vacation destination on its own.

There is an interesting cultural history relating to Hallstatt. Although the term "Celtic" as an ethnic group is often thought to refer to the Irish and/or Scots, it actually refers to a broader group who speak the "Celtic Languages." Interestingly, the earliest archaeological evidence of Celtic culture was found in the salt mines of Hallstatt. The culture developed in this area is known as the Hallstatt culture and refers to peoples from the Early Iron Age in Europe, ca. 800 – 450 BCE. In 1846, a mining engineer, Johann Georg Ramsauer (1795-1874), was searching for pyrite and instead found two skeletons with other artifacts. In all, over 1,000 Celtic graves were unearthed and documented, helping archeologists to understand the importance of salt in the Celtic culture of 700 to 600 BCE. The discovery of these early Celtic relics in the Hallstatt salt caves has changed the archaeological understanding of the Celtic culture (*9*). Many relics can be viewed in a local museum. Hallstatt – Dachstein – Salzkammergut has been designated a UNESCO World Natural Heritage and World Cultural Heritage Site.

The early Celts surface mined salt on the mountain above Hallstatt. You reach the mine (Salzbergwerk) entrance from the south end of Hallstatt town by taking a funicular. Near the top of the funicular is a tower (Rudolfsturm) which was completed in 1284 CE to defend the mine workings. This is one of the pieces of evidence supporting the contention that Hallstatt is the oldest commercial salt mine in Europe.

As in Hallein, the earliest salt production was done by the Celts digging to follow the salt rock veins. It was soon found that it was more efficient to dissolve the salt into brine. The brine could then be brought to the mine face and heated in "salt pans" to obtain the salt by evaporation. Eventually the wood needed for heating became rare in the Hallstatt area. The solution here was to find a way to transport the brine to Ebensee for processing. The pipeline from Hallstatt to Ebensee is the oldest active industrial pipeline in the world. In 1597 the track was begun to allow the pipeline to be constructed. To enable the brine to flow freely, the pipeline and path slope slightly down. Thus, unlike the pipeline from Berchtesgaden to Bad Reichenhall, pumps were not needed to get the brine from mine to processing location. The pipeline required 13,000 tree trunks (pine and fir) to cover the distance. It was put into operation in 1607 and has been in continuous operation ever since, but today, the brine flows through plastic pipes. Above the pipeline is the Brine Pipeline Trail (*10*). Hiking this trail or driving between Hallstatt and Ebensee provides wonderful views of this beautiful part of Austria.

The end of this salt story is in Ebensee. A salt evaporation pond was built in 1596 to receive the brine piped the 40 km (25mi) from Hallstatt. This area was chosen because available wood in the surrounding forests would provide fuel for the evaporation. In 1883, in addition to salt processing, Ernest Solvay (1838-1922) established a soda works. Additional history of the area includes Nazi activities during World War II at the Ebensee concentration camp (nicknamed Zement) and the building of giant tunnels to develop a Nazi rocket research area (*11*).

And so the history of three separate but related salt mines provides a variety of experiences to understand the early Celtic activity in this area: the similarities and differences in salt mining and salt processing, depending upon the times, the politics and the surroundings; and an opportunity to explore the beautiful landscape of southern Germany and southern Austria.

Carinthia: Iron and Rare Earths

Traveling south from Salzburg into Carinthia, Austria's southernmost state, our scientific focus changes from salt to iron and rare earth metals. Iron was mentioned in the earlier part of this chapter but its importance becomes more evident as we journey into this area of Austria. The technology of the rare earth elements, which were initially obtained from further east in Austria, is one of the interests we will explore. The mining and smelting of iron will be the other focus. Again we will find that the initial mining of iron was done by the Celts. But we will also have opportunities to learn more about the later Celtic cultures.

Just as Salzburg was the hub for our earlier adventures, now the hub switches to the small town of Althofen in Kärnten (Althofen in Carinthia). The adjacent towns of Althofen and Treibach, in the township of Althofen, play a part in the story of chemistry and industry in Carinthia (Figure 6). As in other parts of Carinthia, this area was occupied by Celts from Hallstatt, to be followed in about 600 CE by a settlement of Slavic people. Soon political control rested in the estates of the Bishops of Salzburg and his followers. The Althofen castle (burg) was the residence of the local bailiffs and played a part in the Austrian-Hungarian conflicts over the following centuries. Althofen, on the heights above Treibach, became the marketing and religious center of the area (*12*).

Marketing importance dates to 1230 when Althofen received the marketing rights to the iron from the nearby mines of Hüttenberg. A Catholic church was first built at the top of the hill in 1307. The present parish church is towards the top of the hill and still has many of the features of the earlier church. Treibach, in the valley below Althofen, gained importance as a production site accelerated by the construction of an ironworks in 1897. The industrial development was made possible by the Gurk River providing a source of power.

The development of industry in Althofen/Treibach and the compelling story of Baron Carl Auer von Welsbach is discussed in Chapter 12, which also describes the museum founded in Althofen in his honor. One needs to spend a period of time slowly going through the museum to gain an understanding of the variety and significance of scientific development and industry that originated in this small Austrian town (*12*).

Treibacher Industries began with the purchase of the iron works in 1897 by Auer von Welsbach. From iron products it expanded to become the production home of the rare earth or Mischmetallen products utilizing Auer's patents and processes. Mischmetal or "mixed metal" are alloys of rare earth elements which occur naturally (*13*). While the pegmatite and monazite mineral deposits of

Carinthia and Styria in eastern and southern Austria contained rare earth elements, chiefly cerium and lanthanum (*14*), Auer's major sources were the byproducts of his extraction of thorium from Brazilian monazite sands (*15*). A visit to the Treibacher complex is amazing. One significant fact is that almost all cigarette flint spark lighters are based on the Auer patent and are produced in Treibach. Millions of Auer metal flints, composed of a mixture of mischmetal and iron are produced each year in Treibach (*16*).

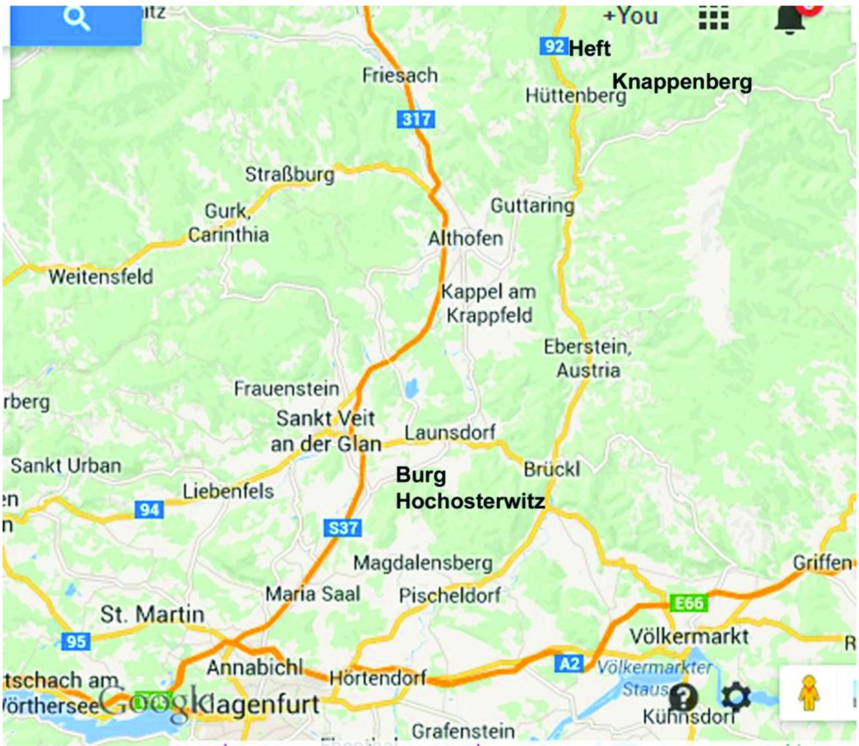

Figure 6. Map of the Althofen Environs. To the northeast lie Hüttenberg, Knappenberg and Heft; to the east lies Gurk; due south lie Burg Hochosterwitz and Magdalensberg; farther to the southwest lies Klagenfurt. @2014 Google.

Knappenberg, Heft, Hüttenberg

Another excursion easily accomplished from Althofen is a visit one valley east to Knappenberg, Heft and Hüttenberg. Now the story turns to iron. Mining the natural products hidden in the mountains surrounding the town of Hüttenberg (N46.9397 E14.5486) dates to Celtic times. "Ferrum noricum" or "Noric steel" was obtained by surface mining on the top of the mountains. Recent archaeological research indicates that iron production in this area began in the 2nd half of the 1st century BCE and lasted to the middle of the 4th century CE, almost the entire time that the Roman Empire exercised its hegemony in this part of the world. Complete furnaces have been recovered and increasing evidence of production activities has been brought to light (*17*). A trip to the Knappenberg (N46.9360 E14.5650) exhibition mine and minerals museum (Figure 7) allows an exploration of mining techniques and traditions from Celtic days up to the year the mine closed in 1978. Donning a hard hat and yellow slicker and following your guide into the mine gives you a better understanding and appreciation of the trials of obtaining iron for a growing technological world. The museum also has a wonderful collection of minerals which was, in itself, worth the experience (*18*).

From Knappenberg, a short drive north takes you to the ruins of the High Ovens of Heft (N46.9511 E14.5690), numbering among the most impressive industrial monuments in Carinthia (Figure 8). Remaining are ovens with one meter thick walls which represent the major transition toward modern blast furnace recovery of usable iron from the ore of Knappenberg and surrounding areas. Although much is in ruin, there are informative signs and work is being done to make the site more informative. It is worth the side trip to see these massive stone works which were operative from 1857 to 1908 (*19*).

As you return to Althofen, you pass through the town of Hüttenberg. A wonderful stop here is the Heinrich Harrer Museum. Heinrich Harrer (1912-2006) was a native son of Hüttenberg, but he is more recognizable as the teacher of the Dalai Lama as presented in the 1954 book and 1997 film "Seven Years in Tibet." The museum documents Harrer's youth in Hüttenberg, his geographical explorations, ethnographic expeditions and mountaineering achievements, as well as his amazing story of his Tibetan adventures. Most fascinating are the two stories devoted to Tibetan culture and religious practices. The 14th Dalai Lama took part in the dedication of the museum and visits it regularly. Rising across the road from the museum is a Tibetan prayer wall complete with hundreds of prayer flags. If you can take the heights, it is a wonderful and moving climb (*20*).

Figure 7. Knappenberg Mining and Mineral Museum. To the left is the exhibition mine entrance. Photograph courtesy of Terry Eyrich.

Figure 8. Philatelic representation of the High Ovens of Heft. From the stamp collection of Daniel Rabinovich, with his kind permission.

Gurk

Approximately 20 km (12 mi) west/northwest of Althofen on the Gurk River is the small town of Gurk, which was the medieval spiritual center of Carinthia. The earliest written record of the city dates back to 831 CE; the Archbishop of Salzburg's court was held there in 864. In 975, the Emperor Otto II sanctioned the opening of a nunnery, which later became a Benedictine Abbey due to the support of Hemma, Countess of Zeltschach (later Saint Hemma or Emma). In 1072 the abbey was dissolved and became the home of the newly founded diocese of Gurk, under the control of the Archbishop of Salzburg. The Bishops of Gurk were in constant rivalry with their "lords" in Salzburg.

The current Gurk Parish Church was previously known as the Cathedral of Gurk, originally built in the 12th century and ranked among the most important Romanesque buildings in Austria. The ancient core can be seen in the crypt noted for its 100 columns. Later additions of Gothic vaults and frescos, Renaissance frescoes, and Baroque interiors make for an excellent tour of the varied architectural styles housed in one building. Of interest to a scientist is the large lead Pietà found in the center of the church (Figure 9). It remains there today because Napoleon's forces failed to remove it: it was too heavy due to the density of lead. The tall 60m (200 ft) twin steeples can be seen from a great distance as you approach the town. The Gurk Cathedral is on the list for consideration as a World Historical Site (*21*).

Figure 9. Lead Pietà in the Cathedral of Gurk. It remains in this church to this day due to the high density of lead which prevented Napoleon's soldiers from removing it to France. Photograph courtesy of Janan M. Hayes.

Burg Hochosterwitz, Magdalensberg, Klagenfurt

Another day one can take another adventure from the hub town of Althofen. This time travel will be to the south. The first stop is an opportunity to immerse yourself in the medieval atmosphere of Burg (Castle) Hochosterwitz, situated on a steep and towering 150 m (520 ft) high Dolomite rock, making it one of the most impressive medieval fortresses and strongholds in central Europe. The winding access path is blocked by 14 fortified gates, which made the castle virtually impregnable. Since 1993 visitors may take an inclined elevator instead of the winding path to reach the entry to the castle proper. Touring through the castle you are able to visit wonderful rooms, displays and dioramas which represent all aspects of medieval life. The weaponry and battle attire are particularly intriguing. But you should also plan to spend time in the church and to examine the family displays: the castle has been in the same family since the 16th century. Visitors can also enjoy lunch at the café on the valley level entrance (*22*).

A short distance further south brings you to the site of Magdalensberg, an ancient Roman city on the east side of the Magdalensberg Mountain, and the Archaeological Park Magdalensberg. This is one of the most important historico-cultural sites in Carinthia. It is older than the Roman Province of Noricum and through the tours and displays at the park you will be introduced to the progression of the Roman settlement of the area. Archaeological research has been going on here since the 1830's. Discontinued during World War I, it was resumed in 1938 and progressed actively every summer since the end of World War II. The museum and park are open from 1 May to 10 October. In addition to observation of actual ongoing research, the park visit includes many displays and explanatory signage. The open area is divided into 22 separate exhibitions presented in the original ruins which have been partly reconstructed (Figure 10). Areas to be visited include the Forum or center of the city; the Tabernae which are accommodation, work and commercial areas; an iron exhibit which tells the story of "ferrum Noricum," including a smelting furnace; and other reconstructed houses for various crafts (*23*).

Approximately 50 km (30 mi) south of Althofen is Klagenfurt, the capital of the state of Carinthia. It is located on the Wörthersee and its old city center is a wonderful place to visit, much of it a pedestrian zone and full of many Renaissance buildings. Some places of particular interest are the Landhaus, Palace of the Estates, which houses the Hall of Shields (Grosser Wappensaal) with its collection of 665 coats of arms belonging to members of the Carinthian estates. A fine Baroque cathedral built by the Protestant Estates of Carinthia is worth a visit. In the central square, or Neuer Platz, is the Lindwurm fountain carved in 1593 from a single block of schist with a massive statue of Hercules added in 1633. The Lindwurm is the winged dragon who lived in the adjacent lake subsisting on a staple diet of virgins. The fountain celebrates its slaying, which allowed the founding of the city. The nearby Wörthersee is a site of water-related activities all year round.

Figure 10. Magdalensberg Archaeological Site. Photograph courtesy of Terry Eyrich.

Conclusion

What can we learn from a scientifically oriented visit to these beautiful alpine vistas? As we have seen elsewhere in this volume, the equally beautiful panoramas of northern Scandinavia yielded up a rich treasure-trove of minerals from which over 20 elements were isolated and identified. We also learned that the mining operations in Sweden and Norway contributed enormously to those countries' wealth, leading to the foundation of Schools of Mines that impacted the development chemistry for over two centuries. The work of unforgettable pharmacists and chemists like Jöns Jacob Berzelius and Carl Wilhelm Scheele enriched the literature of inorganic and analytical chemistry. Not so in Austria and Southern Germany. Why is this? In my humble opinion, we are dealing here with a very old culture that was interested in exploiting the natural resources of the area for purposes of, first of all, in the case of the Celts, survival. Then when the Romans moved in, the area became "colonized" and its whole purpose of existence was to enrich the coffers of the Empire. This attitude continued under Christian auspices because gradually, Christians and Romans became almost synonymous – as we note the influence of the Catholic bishops in the area throughout most of its long history. In general, the powers-that-be were more interested in developing technology rather than science, and the fact that the earth was rich in salt and iron, and not much else, was a defining factor. It was only when Baron Carl Auer von Welsbach came on the scene, as documented in Chapter 12, that we see groundbreaking developments in inorganic and analytical chemistry, chiefly in the area of the rare earth elements. These factors do not make this part of the world any less interesting – in fact, the intimate mix of technology, economics, religion, and ancient cultures render it unique in all the world.

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Chapter 14

Points East: Selected Science Sites of Central and Eastern Europe

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This chapter is meant to give the scientifically curious visitor a taste, while not exhaustive, of what can be found in some eastern European countries, most of which were once part of the communist bloc. Once virtually inaccessible, they now beckon. The first two sites are in Vienna, the gateway to the east. Then the incomparable lure of Prague, Budapest, and Saint Petersburg await.

Vienna, Austria

Museum of Natural History (Naturhistorisches Museum) Vienna

Maria-Theresien-Strasse, Burgring 7, 1010 Vienna, Austria

The Museum of Natural History Vienna (Figure 1) is one of the oldest natural history museums in the world. The collections were begun in 1750 by Emperor Franz Stefan (1708-1765), elected Holy Roman Emperor in 1745. The collection was moved to its present site in 1765 by his wife, Maria Theresa (1717-1780) after he died. The thirty-nine exhibit halls combine collections of art and history. Among the special holdings of the museum are taxidermy specimens of various species of animals that are now extinct or endangered. The museum's collection includes the 25,000-year-old figure of the "Venus of Willendorf" (*1*), an almost-complete skeleton of Steller's Sea Cow (which became extinct more than 200 years ago); a large insect collection, and dioramas showing the habitats of many of the world's animals.

In Science History: A Traveler's Guide; Orna;

Figure 1. Interior view of the dome of the Museum of Natural History Vienna. Photograph by Roger Rea.

As is the case for many museums of natural history around the world, this museum holds more exhibits than a tourist with limited time to view them can see in a day. In 2014, the Museum reported having nearly 40 million artifacts and specimens in its permanent collection. The exhibits that may be of interest to chemists are the exhibits of precious stones and the meteorite collection.

The meteorite collection is the largest in the world, with more than 1,100 specimens on display (Figure 2). The most recent addition to this collection is the Tissint Martian meteorite. This meteorite, which has the same chemical composition as the rocks on Mars, was witnessed to fall on July 18, 2011 over the desert of southwest Morocco near the city of Tissint. It is only the fifth meteorite ever collected after it was observed falling to earth (*2*). Other parts of this meteorite are on display in various museums around the world, and some are even up for sale.

The precious stone and minerals exhibit, housed in the Gem Hall, contains a giant topaz (117 kg), one of the largest topaz crystals in the world. The signature piece in this exhibit is "Maria Theresa's flower bouquet of precious stones," (Figure 3) which she had made as a present for her husband, Emperor Franz Stefan, the founder of the museum.

The museum is near the University of Vienna at: Maria-Theresien-Strasse, Burgring 7, 1010 Vienna. Tel.: + 43 (1) 521 77 – 0. The visitor's entrance is at Maria-Theresien-Platz, 1010 Vienna (*3*).

Figure 2. Meteorite in the Museum of Natural History Vienna. Photograph by Roger Rea.

Figure 3. Maria Theresa's Flower Bouquet of Precious Stones. Photograph by Roger Rea.

Narrenturm (Vienna Pathological-Anatomical Museum)

Spitalgasse 2, 1090, Vienna, Austria

Europe's oldest building to house and treat mental patients is the Narrenturm, built in 1784. When it was constructed, it was outside of what would have been the city limits of Vienna. The Narrenturm (which translates as "Fool's Tower") is a five-story building built to look like a circular fortress. There are 28 centrally-heated cells on each floor of the building where inmates were housed. The cells surround a central courtyard in which doctors could supervise their patients. A total of 139 inmates could occupy the facility at any one time.

Prior to the construction of the Narrenturm, the so-called "insane" were mistreated by relatives or put on display as a circus act or as part of a "freak show." Citizens from Vienna often took weekend trips to the facility to catch a glimpse of what they considered "odd behavior." The windows on the Narrenturm were small slits (to prevent patients from escaping through the windows), so viewing "the crazy people" from the ground was next to impossible. Townsfolk used the cracks where the stones met to climb the walls to get a better view. The response was simple and effective: the lowest fifteen feet of the building had concrete applied (Figure 4) to fill all of the cracks, providing a smooth surface with no "climb points"!

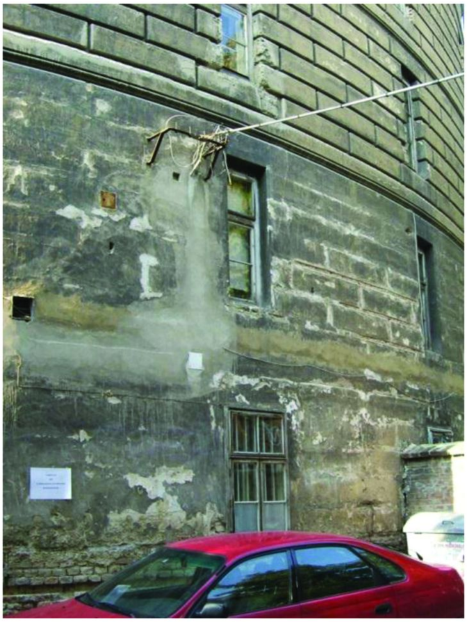

Figure 4. The first two stories of the Narrenturm had concrete applied to the joints where stones met to prevent people from climbing the building to view the patients. Photograph by Roger Rea.

The patient cells are fully equipped to treat mental illness in the manner typical in the 1800s (Figure 5). Rooms were devoid of any objects that could be used by patients to harm themselves or others; chains in the cells are bolted to the floor or wall to restrain patients; large tubs were present in some treatment rooms to plunge patients into cold water (apparently to "bring the patient back to his senses"); chairs and tables had straps to restrain the patient; and electrical probes were used to administer "shock therapy." The Narrenturm was used to house the mentally ill from 1784-1866.

Figure 5. Typical patient treatment room at the Narrenturm. Photograph by Roger Rea.

The tower is now used to house Vienna's Pathological-Anatomical Museum. Over 4,000 specimens of physical abnormalities and deformities are on display – some are preserved in formaldehyde to show external features of the deformity, while others are skeletons showing the actual bone deformity. Each specimen has a description of the type of disease or abnormality causing the deformity. Skulls and bones with holes caused by cancer are on display, as are syphilitic skulls that resemble Swiss cheese. Fetuses with all manner of birth defects are preserved in formaldehyde.

One of the most significant exhibits is one of the world's largest collections of wax reproductions of diseases that date back 100 years or more. Many of these diseases have been eradicated or are very rare these days. The wax displays are full-color, and show the progress of each disease from first infection to full-blown symptoms. Medical students learn how to diagnose diseases using these displays. This allows them the opportunity to learn the pathology of the disease even though the students do not have patients to examine who have the actual disease.

Four types of exhibits are used in the museum: (a) maceration preparations (in which soft tissues are removed from the body by bacteria or chemicals); (b) wet preparations (parts of the body preserved in formaldehyde); (c) moulages (castings in wax); and (d) devices used to treat patients.

Some 50,000 items are on exhibit in the museum. The museum, now owned by the University of Vienna, is open Wednesdays 10.00-18.00, Saturdays 10.00-13.00, and is closed on public holidays. It is located at Spitalgasse 2, 1090 Vienna. Tel: +43 (0)1 406 86 72 2. The website (*4*) is in German, but an English description of the museum can be found at another site (*5*).

Prague, Czech Republic

Klementinum

Mariánské náměstí 5, Prague, Czech Republic

The Klementinum (Clementinum in English), so named because it is located near the former Dominican monastery of St. Clement near the Charles Bridge in Prague, is the second largest complex of buildings in Prague (the Prague Castle ranks first). The Jesuits arrived in Prague in 1566, purchased land surrounding St. Clement Church and created the first Jesuit College in Prague, which they named the Klementinum. The main construction period of the complex spanned a century and a half, from 1578 to 1726. It sprawls over two hectares (roughly 5 U.S. acres) of land near the Vltava River. The two main attractions for scientists are the Baroque Library Hall and the Astronomical Tower.

The dominant architectural feature of the Klementinum is the Astronomical Tower. At 68 meters high, it is the premier viewing platform for Prague. The 172 steps to the top, constructed when people were shorter than most are today, are not for the faint-of-heart, those who need a handrail for steadiness, or those unwilling to crouch a bit to avoid hitting your head on the stairway overhead. But the spectacular, unobstructed views of Prague from the top of the tower make the effort worthwhile.

The Tower's history is closely linked with astronomy and mathematics, subjects taught by the Jesuits at the college they founded here. In about 1750 the tower was fitted with astronomical and meteorological instruments. This allowed for measurements of climatic conditions and observations on the positions of planets to be recorded and tracked. Meteorological records dating to 1775 are preserved in the library nearby – the longest continuously recorded weather and climate records in the world. On the trek to the top of the Tower, visitors will see two 18th century telescopes and a device for measuring the precise movements of the moon (Figure 6).

The Tower is capped by a sculpture of Atlas holding the celestial sphere, an appropriate topping for a building in a city where meticulous astronomical records were recorded by Tyco Brahe (1546-1601) and later interpreted by his student, Johannes Kepler (1571-1630), to determine the movements of the planets in the heavens. The tower was used for astronomical observations until the 1930s. While the Astronomical Tower was not built until 1722, well after Brahe's death, it is fitting that you get one of the best views of his burial place, the Church of Our Lady before Týn (Figure 7), from its viewing platform. The Church of Týn is in the Old Town Square, near the 600-year old Astronomical Clock.

Figure 6. Instruments Used to Measure and Record the Movements of the Moon. Photograph by Roger Rea.

Figure 7. Church of Our Lady before Týn, Tycho Brahe's burial place, as seen from the Astronomical Tower at the Klementinum. Photograph by Roger Rea.

Also located in the Klementinum complex is the Baroque Library Hall. There you will find magnificent frescoes on the ceilings with themes from both science and art, a large collection of ancient books on the original library shelves, and several rare, large globes. Today, the library is part of the Czech National Library, with a total collection of over 6 million volumes.

Admission to the museum is by guided tour only beginning daily at 10.00 until 17.00 (16.00 in winter). There are three entrances into the Klementinum complex. The ticket booth is found at: Mariánské náměstí 5, Prague 1 – Old Town. Phone: + 420 222 220 879. A good preparation for a visit is its English website (*6*).

Heyrovský Institute

Dolejškova 2155/3, 182 23 Prague 8, Czech Republic

Jarsoslav Heyrovský (1890-1967) is the only Czech scientist to have received a Nobel Prize. He was born in Prague and received his Ph.D. from Charles University in Prague in 1918. He continued his studies at University College, London where he worked with F. G. Donnan with a special emphasis on electrochemistry. Heyrovský was fascinated by electrochemistry and decided to concentrate his research work in that area of chemistry.

In the 1920s, Heyrovský began to develop the technique of polarography. In 1924 he invented the Polarograph, an instrument that recorded the composition of chemical solutions by measuring current vs. applied potential. He perfected the use of the dropping-mercury-electrode for qualitative and quantitative analysis of oxidizable and reducible substances in solution (Figure 8). In electrochemical experiments that use solid electrodes in contact with a test solution, the solid electrode will often oxidize and/or react with the solution, effectively "poisoning" the electrode. The advantage of a dropping-mercury-electrode is that the electrode surface constantly renews with each drop, eliminating the effects of electrode poisoning.

Within ten years of the invention of the Polarograph, this method of analysis was in common use by chemists. Heyrovský devoted his remaining career to polarography and received the Nobel Prize for his work in 1959. It is unusual for a chemist to initiate an area of chemistry and remain a central figure in the full development of that specialty.

Memorial plaques marking the progress of Heyrovský's career abound in Prague.

- His birthplace in the Old Town house named „Na Kocandě" at Křižovnická street No. 20 (N: 50.0878 | E: 14.4153) contains his bust and original desk. (At this writing, the house is undergoing restoration.)
- On 10 February 1922, Heyrovský invented polarography in a basement laboratory of the university's Chemical Institute (Hlavova 2030, New Town; N: 50.0683 | E: 14.4248)
- Heyrovský's residence at Ladova 7 (N: 50.0701 | E: 14.4168) in the Albertov district of Prague from 1926 until 1950

- In 1950, Heyrovský´s great dream of having an independent Polarographic Institute was realized when, near Wenceslas Square, the Czechoslovak government established the Central Polarographic Institute under his directorship. In 1953 the Institute came under the auspices of the Czechoslovak Academy of Sciences and was eventually moved to Vlašsská street No.9 (Lesser Town; N**:** 50.0868 | E**:** 14.4001), Heyrovský worked here until his death. His Nobel Prize medal and diploma have been kept at this location since December, 1959.
- Heyrovský's remains were entombed in Vyšehrad Cemetery (Soběslavova 89, 128 00 Prague 2; N**:** 50.0647 **|** E : 14.4181) next to the grave of his classmate, Czech writer and playwright Karel Čapek (1890-1938); they were later moved to the family plot. Vyšehrad Cemetery is the Czech Republic's "Westminster Abbey," where its notable citizens such as composers Antonin Dvořák and Bedřich Smetana are buried. Since these locations are scattered throughout Prague, GPS coordinates are supplied in lieu of a map.

Figure 8. One of the First Polarographs Equipped with a Dropping-Mercury-Electrodes Heyrovský Used. Photograph by Roger Rea.

Today the Heyrovský Institute of Physical Chemistry conducts fundamental research and is engaged as well in educating both undergraduate and graduate students. It has about 150 full-time employees and 50 graduate students at any one time. While the Institute is not a museum in the traditional sense of the word, it does house and display some of Heyrovský's original equipment.

A most striking feature of the Institute is a large wooden wall, beautifully hand-carved in three-dimensional relief, showing scenes from Prague's history intertwined with the chemical symbols for various elements (Figure 9).

Figure 9. Portion of the Carved Wooden Wall Depicting Scenes of Prague's History, with Symbols for Hydrogen (H), Krypton (Kr), and Molybdenum (Mo). Photograph by Roger Rea.

When Heyrovský received his Nobel Prize in 1959, what was then Czechoslovakia was still under communist rule. His family was not allowed to accompany him to the Nobel ceremony because the political leaders feared that if his family members were with him, he would never return to Czechoslovakia. As a result, his family was denied the opportunity to see him accept his Nobel Prize. The awards ceremony for the Nobel Prize remains a private event to this day – only guests invited to the ceremony are allowed to witness it. In 2005, Heyrovský's son, Michael, received a rare film copy of the 1959 Nobel Prize awards ceremony, showing his father being awarded the Nobel Prize by the King of Sweden (Figure 10). The film may be available to the visitor for viewing.

The Heyrovský Institute (*7*) is located at: Dolejškova 2155/3, 182 23 Prague 8, Czech Republic. Because the Institute is not a museum, visitors should contact the facility to arrange a visit. The phone number is: +420 286 583 014 or +420 266 052 011. The Institute is accessible by taking Metro Line C (Red line) to station Ládví. Go upstairs and follow the arrows towards, "Bus Prosek Ďáblice." When you come out on the street, go about 150 meters to a crossroad with traffic lights, turn to the left and you will see the tall, beige-colored building of the Institute.

Other institutions of scientific interest are scattered around Prague. Among them are the Strahov Library (described in Chapter 1 of this volume) and the National Technical Museum in Prague. The latter is fully described in an article by Paul and Brenda Cohen as part of their series, Finding Science Past and Present (*8*).

Figure 10. Jarsoslav Heyrovský Waits to Receive his 1959 Nobel Prize from the King of Sweden. Photograph by Roger Rea. Reproduced with the kind permission of the Heyrovský family.

Budapest, Hungary

The Semmelweis Medical Historical Museum (Semmelweis Orvostörténeti Múzeum)

H-1013 Bp. I., Apród útca 1-3

Introduction

What with modern medicine's battery of prophylactic drugs along with its tools of amniocentesis and ultrasound, having a baby these days is probably no riskier, on average, than taking a bus ride. So it is easy to forget that childbed fever ravaged maternity clinics and wards worldwide as recently as a mere hundred or so years ago. It was Ignaz Semmelweis who put his finger on the problem and solved it very simply, although the medical establishment of his day rejected him outright. Today, the Semmelweis Medical Historical Museum maintains a comprehensive collection of artifacts and documents that, taken together, pay tribute to one of Hungary's greatest heroes.

One look at the impressive building (Figure 11) that makes up the basis of the Semmelweis Medical Historical Museum leads one to assume that since it is based in the very house in which its namesake, Doctor Ignaz Philipp (Ignác

Fülöp) Semmelweis, was born, that the good doctor founded and embellished this institution out of his own interest and funds. Nothing could be further from reality.

Dr. Ignaz Semmelweis: A Brief Biography

Ignaz Semmelweis (1818-1865), though born in this very house, took his medical degree in Vienna and spent much of his professional life in that city. In his work at two maternity clinics at the Vienna General Hospital, he noticed that maternal mortality rates due to puerperal fever (sometimes called childbed fever) differed widely between the two. The first, staffed mainly by physicians, had an average rate of about 10%, whereas, the second, attended mostly by midwives, had a rate often under 4%.

Figure 11. The Semmelweis Medical Historical Museum, Budapest. Photograph by Mary Virginia Orna.

A chance accident helped him to understand this wide variation. A physician colleague of his was accidentally punctured by a student's scalpel which had recently been used to cut open a cadaver. The colleague soon exhibited similar symptoms to puerperal fever and died a short time later. Since most of the physicians at the hospital divided their time between performing autopsies and attending to women in labor, Semmelweis saw an immediate connection: he hypothesized that the physicians' hands were contaminated by what he called "cadaverous particles" that they subsequently transmitted to their maternity patients, whereas the women attended to by midwives ran no such risk.

In 1847, Semmelweis instituted a policy of hand-washing with a chlorinated solution in the clinics and witnessed a dramatic decrease in the mortality rate. However, since his conclusions were mainly empirical, without a shred of theory to back him up since this discovery predated Louis Pasteur's germ theory by several decades, his recommendations were not accepted by the medical establishment. In fact, Dr. Semmelweis was downright vilified even though his views were gaining acceptance in many institutions throughout Europe. The conflict raged over the better part of a dozen years during which Semmelweis was relieved of his position at the hospital. In 1861, he published a book on his views that met with strong resistance from the medical community despite the fact that he could demonstrate unqualified success with his method, thereby saving hundreds, perhaps thousands, of lives.

Frustrated in his efforts, with which he had become obsessed, he began a gradual descent into dementia that ended with his tragic death: lured to a Viennese insane asylum in 1865, he was straightjacketed and beaten by the guards and left neglected in a darkened cell. He died two weeks later of severe internal injuries.

Today, Semmelweis is hailed as the "savior of mothers" not only in his home country of Hungary, but throughout Europe. In addition to the Semmelweis Museum of Medical History, there are clinics, hospitals, and universities that bear his name in both Hungary and Austria. Essentially, Semmelweis is recognized today as a pioneer in antiseptic policy. He suffered for his views, as have so many others throughout history whose insights and discoveries were far ahead of their time.

The Collection of the Semmelweis Medical History Museum

In 1965, exactly 100 years after Dr. Semmelweis's death, the museum opened its doors and it stands today as a tribute to Hungary's favorite medical son. Together with the National Medical History Library, established in 1951, and the Archives, active since 1974, it makes up the most important research basis of Hungarian medical history. Over the 5 decades of their existence, the collections of the museum became very extensive, and today they form one of the richest medical and pharmaceutical historical collections in the world. Although the museum's collection target embraces the whole of the Hungarian medical system, these artifacts are naturally supplemented by material that represents the development of all of western medicine from the prehistoric age to the beginning of the 20th century, with a special emphasis on the development of Hungarian medicine and the work of Semmelweis.

The original concept in building the museum's collection was to acquire as many artistic objects as possible, and to present the culture of curing, of medical thought and theories throughout the ages. The core of the permanent exhibit does precisely that by presenting the history of western medicine arranged in essentially chronological order. Visitors are guided through a series of exhibit cases (Figure 12) that document medical practice from ancient Egypt up to modern times. Represented are displays on the development of biological knowledge, techniques used in surgery and obstetrics, exhibits of scientific books, documents, paintings, statues, etc. The artistic expressions of disease, death and healing are documented as well. Visitors can also gain knowledge about the role of pharmacy and medicine in different civilizations and ages, that is, the versatile and ever changing traditions of the culture of western medicine.

Figure 12. Some Display Cases on the History of Early Medicine. Photograph by Mary Virginia Orna.

Some unique items in the exhibit are a 1543 copy of anatomist Andreas Vesalius's (1514-1664) *The Structure of the Human Body in Seven Books*, a 1628 copy of William Harvey's (1578-1657) *Discourse Concerning the Generation of Animals*, and a beautiful wax anatomical figure (nicknamed "Venus Anatomica") demonstrating the female lymphatic system from the Florentine school of Felice Fontana (1730-1803). Several references (*9–11*) describe the museum's holdings in greater detail.

Each year, the museum also hosts temporary exhibitions dealing with healing methods, artistic activities connected to medicine, and the development of medicine in the light of its connections with natural science, economic, cultural and political history. It does not take the visitor long to realize that the care and attention given to the exhibits as well as the details documented in the displays is truly a work of love. However, although each display case contains a description of each item in English as well as Hungarian, the overall theme of each is described only in Hungarian – thus necessitating an English guidebook for the truly interested. The museum's website (*12*) is a very helpful introduction to the exhibit.

The Origins of the Museum

How did this marvelous collection of artifacts come to be? And how did it come to be housed in the birthplace of its eponymous honoree? It is clear from Dr. Semmelweis's brief biographical sketch that he had nothing to do with the museum's origins or development. First, let's take a look at the building.

The original building was destroyed by fire in 1810, but was reconstructed with its present façade prior to Semmelweis's birth there in 1818. 125 years later, it survived, but in a very poor condition, the 1944-45 siege of Budapest. The northern wings were razed to the ground and although the walls and some floors of the middle and the southern parts remained. In the 1950s, it was earmarked for total destruction, but after the 1956 Hungarian Revolution, it became a pawn to further the reconciliation policies of the new Kádár regime. János Kádár (1912-1989), the new communist leader, in sharp contrast to the blatant aggressiveness of the Stalin years, wanted to good will towards various professional groups, including physicians, provided that the groups were not openly anti-communist or anti-Soviet. Thus it was that the medical profession was given a museum, named after the probably most famous Hungarian doctor, in the very house where he had been born, and where medical circles could present the sophistication and excellence of their profession. It was a thoughtful policy, as the museum really did contribute to the cultural level of both the city and the country. It attracted tourism, and was able to produce serious research in a field which was presumably far-removed from politics.

Regarding the building: many of the pre-1944 houses survived the siege, even though the city's deterioration could only be compared to that of Berlin and of Warsaw. Prague, Vienna and Munich were more fortunate, though Dresden was not. In 1865, Semmelweis was buried in Vienna; in 1891, his remains were transferred to Budapest, and finally, in 1964, they came home to his newly reconstructed birthplace (Figure13).

Regarding the collection: it came partly from other Hungarian museums (the museum network was reorganized during the 1960s), and from collections of disbanded civic organizations, and from the possessions of suppressed religious orders (due to sovietization in the 1950s), such as the Royal Association of Budapest Physicians, and the Brothers of Mercy. The collection was enriched and enlarged by donations from hospitals, private individuals, and by purchase. The museum receives government support, as well as private donations, and grants from the European Union.

History of Pharmacy Associated with the Semmelweis Museum

For centuries, the practice of medicine and the compilation and dispensing of medicinal substances were a single discipline. In the Western world, the split came by the decree of Frederick II who separated the two in the faculty of the University of Naples in 1224. From then on, pharmacies and apothecaries began to develop, often associated with religious orders that maintained gardens of medicinal herbs and carried on a healing tradition through their use. Reconstructed within the

Semmelweis Museum as a separate room, the Holy Ghost Pharmacy, one of the three pharmacies in early nineteenth century Pest, contains hundreds of artifacts coming from every part of Hungary (Figure 14). The pharmacy was established in 1786 and quickly became a popular meeting place until well into the nineteenth century.

Figure 13. Grave of Dr. Ignaz Semmelweis. Photograph by Mary Virginia Orna.

Figure 14. The Holy Ghost Pharmacy. Integral Part of the Semmelweis Medical History Museum. Photograph by Mary Virginia Orna.

Another integral part of the Semmelweis Museum is the Golden Eagle Pharmacy, located high up on Castle Hill at Tárnok utca (street) 12. Building upon a collection of Hungarian pharmaceutical artifacts that was begun in 1896, a small exhibition in Buda Castle was opened under the auspices of the medical school of the university, which subsequently transferred ownership to the Semmelweis Museum. When it became necessary for this collection to be moved, it is not by chance that the Tárnok street location was chosen since a pharmacist was operating at the site from the middle of the eighteenth century. The exhibition represents the development of pharmacy via documents and artifacts to show that it is an important part of both science and art history. The highly ornamented ceramics, wood, and glass tools and balances are part of our universal artistic heritage.

From Pest, to reach the Semmelweis Museum at Apród utca, 1-3, cross the Erszebet (Elizabeth) Bridge to Buda either on foot or using one of the many buses, such as the no. 5. The museum is immediately on the other side of the bridge, a stone's throw from the Danube. The reach the Golden Eagle Pharmacy at Tárnok utca 12, on top of Castle Hill, walk north a few hundred yards from the funicular (Budavári Sikló), or an almost equal distance south from the Matthias Church (Mátyás-templom). Hours for both are 10.30-18.00 (16.00 in winter), Tuesday through Sunday.

Museum of Textile and Clothing Industry (Goldberger Museum)

Lajos útca 138, Budapest

Few museums have touched us so much. It is the history of the Goldberger family told as industrial history, but chock full of science, technology, adaptation to change of circumstances and the tenacity of a dynasty built on brave women who have endured as many as 20 pregnancies in the process. The latter produced many sons and enabled the growth of an extraordinary family tree that blossomed, became ennobled, and ended in the Mauthausen death camp. Always the innovators, the Goldbergers captured the market and at the same time were among the first to look after workers' rights with absolutely incredible provisions (for the time) in health care, sick leave and pension plans that left their competitors in the dust. Yet the rise of National Socialism, the conquest of Hungary by Hitler, the consequent deportations, and the post-war Soviet "five-year plans" that became every more demanding (and impossible) led to the eventual demise of their two-century family business. This museum tells the story, and the story deserves to be told.

Let's back up. Where did the Goldbergers come from? The story starts with the migration of merchant Jews from Bohemia and Moravia to Óbuda (now part of Budapest) in the first half of the 18th century and a mandatory name change that led them to adopt the terminology of a geographical feature in the town: *Arany hegy* in Hungarian became *Gold berg*. The family occupied the present site of the museum (Figure 15) from the latter half of the 18th century onward.

Figure 15. The Museum of Textile and Clothing Industry as it appears today. Photograph by Mary Virginia Orna.

Ferenc (1755-1834), in 1784, founded a small indigo vat-dyeing plant in the courtyard of the family home. Since dyeing requires large amounts of water and drying linen needs a fair amount of space, the location of their home near the Danube as well as being surrounded by unbuilt lots proved to be ideal for such an enterprise. Ferenc began with 3 indigo-dyeing tubs and 3 printing tables. The raw linen came from Moravia and Upper Hungary, and the indigo dye from a merchant in Pest.

The process was very labor intensive and seasonal, with the greatest activity extending from early spring into late fall. The raw linen was boiled for hours in a potash (potassium carbonate) bath, thoroughly rinsed and then dried on wooden frames or laid out in a field. The scoured, bleached, clean and dry linen was soaked in hot starch solution and when cool was manipulated manually to distribute the starch evenly, rendering the material smooth and suitable for dyeing. In the mangle room, the cloth was smoothed out first by a manual, and later by a horse-drawn cog-wheel mangle. (The mangle, 12 to 18 feet long and 6 to 9 feet high, consisted of a thick beam and a huge chest rolling back and forth loaded with heavy stones, ironing the cloth rolled on a cylinder.) Meanwhile, the indigo dye was extracted from the indigo plant leaves imported from India by crushing, soaking, fermentation, filtration, oxidation, and drying. The dried indigo cakes then had to be chopped and powdered. Alum, iron and copper sulfate had to be prepared by grinding in iron mortars and stone bowls.

The prepared linen was laid out on a printing table and decorated by printing with wooden blocks dipped in a resist agent, or paste, whose composition was known only to the dyer. It was generally a mixture of gum Arabic, nitric acid, water, sulfuric acid, lard, and the sulfates of lead, zinc, and copper. On average, a worker was able to print about 360 to 450 feet of fabric per day (keeping in mind that the work day was generally from 3:00 AM to 11:00 PM!). After printing, the linen was taken to the tub room where the indigo dye bath was stored in large, in-ground tubs. The linen, hanging on a round or star-shaped wooden or iron frame, was immersed into the tub with a pulley for about 30 minutes (Figure 16). After removal from the tub, the leuco form of the dye turned greenish-yellow, then green, and then blue via air oxidation. This process was repeated several times depending upon the desired degree of saturation. Finally, the cover paste on the linen needed to be worn away with acid solution, then thoroughly rinsed and dried, allowing the previously covered and protected areas on the linen to exhibit the base color, usually white.

Figure 16. A Simulated Illustration of the Dyeing Process in the Tub Room. Foreground: Linen about to be Dyed; Background: Linen already Dyed and Removed from the Tub. Photograph by Mary Virginia Orna.

Blue-dyed materials were used as tablecloths, bed sheets, bedspreads and curtains from the end of the 18th century. Most significant of all was the tablecloth, which served as a flagship of a given workshop since on a relatively large surface the various types of patterns were quite visible, and therefor conspicuously prominent. This is also the period when oil-dyeing came to be considered an independent profession (18th – 19th centuries) and it becomes quite widespread in almost all blue-dyeing manufactories. In the case of oil-dyeing, the dye was mixed with vegetable oils and therefore became more durable; the dye could be applied directly onto the pre-treated colored fabric.

Indigo belongs to that class of dyes commonly known as vat dyes (*13*). Generally, dyes of this type are sold as solid materials in the forms of cakes or powders that are insoluble in aqueous media. In order to solubilize the material, it needs to be first reduced to the leuco acid intermediate which is nearly colorless, then to the soluble leuco salt in the presence of an alkali (in ancient times from wood ash, plant ash or eggshells). The textile to be dyed is then immersed in this solution, and upon exposure to air, the dye will re-oxidize to the pigment within the fibers of the textile. The material can be successively dyed to produce a deeper color, as was the practice of the Goldbergers.

Indigo is one of the few naturally occurring dyes still in use today. One great drawback of most natural dyes has been their notorious lack of fastness, either to light or to washing. Indigo is no exception, but its lack of fastness has actually worked in its favor. What self-respecting teenager would accept a pair of blue jeans that looked pristine and new? It is that worn and faded look, deliberately cultivated, that accounts for indigo's popularity today (*14*). Indigo's chemical structure was first deduced as early as 1868 (*15*), but it took almost another 30 years to develop a commercially viable synthetic process. With that process, the demand for natural indigo dropped dramatically and by the second decade of the 20th century, it was a dead industry (*16*). However, the producers of indigo cloth, like the Goldbergers, were able to reduce many steps in their own process by using the readily available and less expensive synthetic variety of the dye.

The museum consists of three rooms on the ground level of the original Goldberger family home. The first room describes the vat dyeing process by use of simulated vats and a video. It also contains a large collection of the wooden blocks used to print the resist paste onto the cloth prior to dyeing. The second and much larger room contains information on the family business throughout the 19th century and into the first decades of the 20th century, and illustrates the evolution from a labor-intensive, manually dependent industry into a highly mechanized one. The third room documents the trials undergone by the business, first by the Nazis, including the deportation and death of family members in the death camps of the Third Reich, and later by the Soviets, who gradually squeezed the struggling company out of business.

The museum, now part of the district museum of Óbuda, is open Tuesday through Sunday, 10:00 A.M. to 6:00 P.M. It is located in Buda at Lajos utca 136–138 (tel. +36-1-250-1020). Although the website (*17*) is only in Hungarian, there are English captions and explanatory displays throughout the museum. It is a 10-minute walk from the Tímár Utca bus stop, bus no. 86.

Foundry Museum (Öntödei Múzeum)

Bem József útca 20, Budapest

Also on the Buda side of Budapest, there is a place to take you hundreds of years back in history. An old factory building can be found here with saw-tooth like, forefront brick architecture, standing humbly by an old block of flats surrounded by modern high rise buildings. This is the one-time factory of Abraham Ganz (1814-1867), where a foundry existed up until the 1960s. Within the walls of this factory, the world's most renowned railway wheels were once produced. This is the building where the first Foundry Museum in central Europe was opened in 1969.

Ganz, a Swiss, established his foundry in 1845, and it swiftly became world-renowned for its production of trolley and tram wheels by the cold cast iron process patented by himself. Its planned closure in May, 1964, gave rise to the idea in foundry circles to establish this still largely unchanged foundry as a technical monument and at the same time to create a space for the presentation of the development of the Hungarian foundry industry. Though some of the wooden parts of the building were removed, the original building remains largely unchanged with the two cupola furnaces and the rotary cranes still in place. On the building's facade there is a memorial stone that reminds us of the first and last runs of the foundry: 1845-1964.

The foundry industry is one of the oldest industries in Hungary, as documented by archaeological discoveries dating from the Bronze Age. Cast iron was produced in the area 400 years ago, and steel casting has a history of over 100 years. Today's foundry personnel are heirs of the legacies of the past. The Foundry Museum helps to protect this heritage, to preserve the memory and to pass on the legacy to future generations. It now comes under the auspices of the Hungarian Museum for Science, Technology and Transport.

On display are the rotating cranes and the hard cast wheel foundry in their original condition (Figure 17). To the right of the entrance are the ore mixing space, collection pans, ladles, the two cupola ovens and all their auxiliary equipment in working condition. There are displays on the history of metallurgy spanning three and a half millennia. Many useful cast metal products are on display including a collection of stoves from different parts of Hungary, molded cups, statues, and a variety of useful objects (Figure 18). There is also a very detailed and informative video demonstrating the cast-metal process.

For additional information about the museum, please visit its website (*18*), which is the umbrella which is the site for the Hungarian Museum for Science, Technology and Transport, and its affiliates.

Posted museum hours are Thursday and Saturday: 10.00-16.00; Friday 10.00-14.00. Admission fees are 800 HUF for adults; for ages 62-70, 400 HUF; over 70, free. Photos and videos are free, but no flash or tripods are allowed. It is best to contact the museum directly before a visit at ontode@mmkm.hu to make sure that it will be open when you plan to visit.

To reach the museum, take the Metro no. 2 to Szell Kálmán ter, and then take either the 4 or 6 tram 2 stops on Margit Körut. On exiting the tram, walk straight ahead in the direction of the tram, but as the tram curves around to the left on Margit Körut, stay straight on Bem József utca; no. 20 will be on your right in a few hundred yards.

A very popular museum also displayed on the technical museums website is the Transport Museum (Közlekedési Múzeum) located at Városligeti körut 11, in a corner of City Park (Hösök Tere or Széchenyi fürdö stops on M1). Museum hours are: Tuesday-Friday 10.00-17.00 (16.00 in winter); Saturday-Sunday 10.00-18.00 (17.00 in winter). Admission prices: Adults 1600 HUF; 800 HUF for persons aged 62-70; free over 70.

Figure 17. Wheel Foundry Manufactory in its Original Condition. Photograph by Mary Virginia Orna.

Figure 18. Display of Cast Metal Objects. Photograph by Mary Virginia Orna.

Saint Petersburg, Russia

D. Mendeleev Museum and Archives

St. Petersburg State University, Mendeleevskaya line, 2, St. Petersburg, Russia

St. Petersburg, in northern Russia, second only to Moscow in size, is the northernmost city in the world to have a population of 5 million people. St. Petersburg was founded by Tsar Peter the Great (1672-1725), and served as the imperial capital of Russia until 1918. The capital was moved to Moscow after the 1918 Soviet revolution. St. Petersburg is the site of the Hermitage (one of the largest art museums in the world), the deepest subway system in the world (dug deep to get to firm bedrock below the soggy soil on which St. Petersburg is built), and a first-class science museum devoted to Dmitri Mendeleev (1834-1907).

Mendeleev was the most prominent chemist in Russia during the time he worked at the University of St. Petersburg (1866-1890). While at the University, he devised his best-known contribution to chemistry: The Periodic Law (1869). His lesser-known, but equally important, contributions were in the areas of meteorology; geology; and chemical technology (fuels, explosives, and petroleum are examples) to mention a few. The museum is actually a reconstruction of the apartment in which Mendeleev and his wife lived while he worked at the university.

At the time Mendeleev worked at St. Petersburg University, it was common for professors to live in an apartment adjacent to their laboratories and work offices. Mendeleev moved out of the apartment in 1890 and took a job with the Bureau of Weights and Measures. His study has been carefully reconstructed for the museum using archival photographs. His office furniture, library, and the archives on display were purchased from his widow in 1911. The museum has been expanded and improved upon over the years based on input from former students and colleagues.

The museum occupies three rooms that were originally Mendeleev's living room, dining room and study. The former living room now houses memorabilia from his youth and photographs of the guests he entertained in his university apartment in St. Petersburg. The former dining room now contains memorabilia from Mendeleev's life before he came to St. Petersburg. The most complete portion of the museum, and the closest to the original configuration, is Mendeleev's study. Here you will see the desk (Figure 19) where he wrote his periodic law, photographs of his scientific contemporaries, and his large collection of books.

A display of the instruments that Mendeleev used in his work occupies one room in the museum. Among the fascinating items here is a balance that he used in his research on gases. Mendeleev's work involved comparing the masses of two different gas samples contained in large glass spheres in order to study the different compositions of the gas samples. To obtain reliable data, Mendeleev determined that he needed a balance that was more accurate than those that were available in the 1870s. He had a double-pan, equal-arm balance (Figure 20) constructed by Jules Salleron (1829-97), a well-known Paris instrument maker, that would be accurate in detecting mass differences between two gas samples that were as small as 1/15th of a milligram, with the load for the two gas samples as large as 1 kg. The balance is a signature exhibit in the instrument display.

For the adventurous traveler, a short subway ride away from the Museum (take either Red Line 1 or Blue Line 2) is the Technological Institute, where you will find a statue of Mendeleev in front of a giant periodic table built into the wall of one of the university buildings.

Element #101, the ninth transuranium element in the actinide series, is named mendelevium (symbol, Md) in honor of Mendeleev's work on developing the periodic table. A trip to the Mendeleev museum is a "must-do" for chemists visiting St. Petersburg.

St. Petersburg University and the Mendeleev Museum are along the Neva River, just a short walk from the Hermitage across the Dvortsovyy Bridge. The museum is located at: St. Petersburg State University, Mendeleevskaya line, 2. In the summer it is open Monday through Thursday, 11.00-16.00. To visit the museum, call in advance for tickets at: (812) 328-9744 or (812) 328-9737, or visit the museum web site (*19*). Click the button in the lower right-hand corner for the English translation of the web page.

Figure 19. Mendeleev's Desk in his Study at St. Petersburg University. Photograph by Roger Rea.

Figure 20. Double-Pan, Equal-Arm Balance Mendeleev Used in Studying the Composition of Gases. Photograph by Roger Rea.

What Can Be Learned from History

Analysis of the chemical composition of meteorites, such as the Tissint meteorite held in the Vienna collection, can be fraught with peril if the data collected from the analysis are extrapolated too far. A case in point is the analysis of the Allende meteorite which crashed to Earth in Mexico on 8 February 1969. Edward Anders, a world-renowned meteor expert, found that the Allende fragment contained inclusions of chondrules, one of the most primitive forms of material aggregation known. He hypothesized that these "cosmic rocks deprived of geological evolution" were generated by the explosion of a supernova about 4.6 billion years ago.

As in other meteorites as well as in the Allende fragment, an abnormally large amount of two isotopes of xenon, ^{131}Xe and ^{136}Xe, were found. Their origin was a mystery. For Anders, the only explanation for this experimental evidence was the spontaneous fission of an as yet unknown transuranium element. In fact, none of the known transuranium elements at that time gave xenon nuclei as fission products. Anders and his colleague Dieter Heymann (b. 1927) further hypothesized that the ancestor of xenon should be an element between atomic numbers 112 and 119. Three years later, in 1972, he reviewed his hypothesis and set the range of the "superheavies" between 111 and 116; finally, in December 1975, he reduced the number of elements to three: 115, 114, and 113 (*20*).

Then, in late 1983, another article on the superheavy elements appeared, authored by Anders (*21*). It was a retraction of his hypothesis on the existence of primordial superheavy elements entrapped in the Allende meteorite, ancestors of the anomalous isotopes ^{131}Xe and ^{136}Xe. He had found an alternative to the unexplainable abundance of these two nuclei through a new, quite different, hypothesis: the two heavy isotopes of xenon with masses of 131 and 136 would have been formed through nucleosynthesis as a result of neutron capture and would have remained entrapped in the meteorite from time immemorial. The solution to the mysterious abundance of xenon was possible by positing synthesis starting from lighter elements through a thermonuclear process present in supernovae. It is never easy to admit one's errors, even 8 years later! Hindsight is always a clearer lens than foresight.

In 1925, Jaroslav Heyrovský, using his newly discovered polarographic technique, dedicated himself passionately to the search for element 43, eka-manganese, that today we know as technetium. Together with Vaclav Dolejšek (1895–1945), an expert spectroscopist, Heyrovský was aware that some samples of "crude" ores gave results that could be interpreted as admitting to the presence of an element analogous to Mn that was reduced potentiometrically together with manganese. At the end of their chemical and spectral analyses, Heyrovský and Dolejšek concluded that this chemical behavior could very well be the signature of the sought-after element (*22*). Fortunately for the future Nobel laureate, he did not jump in headlong to claim a false discovery of an element, thus saving him considerable possible embarrassment.

When Dr. Semmelweis ran head-on into an intransigent medical establishment that refused to believe that such a simple solution as hand-washing could save many lives, he was not the first, nor the last, person to experience such difficulties. He was accused of not having a theoretical basis for his ideas, but one of the biggest stumbling blocks was the fact that the solution was so simple and applied to every case – in a medical atmosphere that held that every illness was *sui generis*, likewise an assumption that had no theoretical basis. One has only to fast-forward a few decades into the early years of the twentieth century to find the same opposition to the new idea of chlorination of drinking water to realize that political battles and public concern are a common theme and that "revolutionary" scientific advances are rarely free from controversy (*23*).

When Dmitri Mendeleev arranged the then-known elements in order of increasing atomic weight, he noticed a periodic recurrence in chemical properties at certain intervals. However, he had to wrestle with so-called pair inversions of two groups (*24*) of elements (copper-nickel and tellurium-iodine) since placing them in their proper weight order would destroy the groupings according to chemical properties. Hence, he insisted that the atomic weights of these elements were in error, sending some chemists scurrying to "correct" this problem by determining more accurate atomic weights. Little did Mendeleev dream that the weights were correct and his assumptions wrong. It would take two great discoveries, the primacy of atomic number over atomic weight, and the existence of isotopes, to resolve this problem many decades later (*25*).

These incidents related to the content of this chapter indicate that not only justice, but also science, can be blind, either rejecting in the case of Mendeleev or accepting too readily in the case of Edward Anders, erroneous or non-existent theories. One can also fall into the error of placing too much confidence in one's own discoveries, as Heyrovský's near-free-fall indicates. And sometimes being ahead of the curve, as in the case of Semmelweis, can lead to rejection and tragedy (*26*).

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Chapter 15

Scientific Study Tour of Ancient Israel

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More than a dozen scientific techniques have been applied for the study of archaeological artifacts excavated from various sites of Ancient Israel by an international field of researchers. These methods include Amino Acid analysis, Ancient DNA analysis, Accelerated Mass Spectrometry, Atomic Absorption Spectroscopy, Particle-Induced X-ray Emission, X-Ray Fluorescence, X-Ray Diffraction, Fourier Transform Infrared spectroscopy, Nuclear Magnetic Resonance spectroscopy, Electron Microprobe Analysis, Scanning Electron Microscopy, High-Performance Liquid Chromatography with Photo-Diode Array (HPLC-PDA) detection, and Hygric Expansion Coefficient measurements. This paper discusses the significance of the results of the analyses performed with these methods on artifacts found in four representative archaeological sites in Israel, travelling from north to south, over a 450 km stretch of land. The science tour starts in northernmost Tel Dan, the ancestral home of the biblical Tribe of Dan, yielding the extraordinary House of David stele and the royal or priestly bronze scepter head. The results of archaeo-metallurgical analyses depict a portrait of the simple socioeconomic living conditions of the Iron Age inhabitants of Tel Dan from three millennia ago. Travelling down to the dry and hot climate of the Dead Sea area, we encounter a region that was inhabited by a 2,000-year old Jewish sect. This region yielded tens of thousands of fragments from the famous biblical and communal scrolls, which were stored or hidden in the caves of Qumran

In Science History: A Traveler's Guide; Orna;

and nearby areas. Various scientific analyses of the scrolls produced the following results: the parchments were produced from the skins of goats and other local animals, about which there is still an on-going debate; scientific analyses of the black ink used in the scrolls clearly determined that it was not iron-based, but rather carbonaceous (charcoal, soot, lampblack, etc.); the rare red ink found on only four separate fragments was cinnabar (vermilion). Continuing along the Dead Sea route but travelling a bit more south, we arrive at the famous mountaintop of Masada, the 2,000-year old palatial hideaway of King Herod. Scientific analyses of the wall paintings identified the typical Roman-period pallet of inorganic artists' pigments. Chromatographic analyses on textiles from Masada identified the biblical reddish-purple *Argaman* dye on a weave from probably a royal cloak of King Herod, and, on a different textile, the dark bluish-purple (or violet) biblical *Tekhelet* dye was found. On the last stop of our science tour, just before we arrive at the southernmost point of Israel on the Red Sea, is the Timna Valley, which was an ancient copper-mining area, originally believed to have been mainly used during King Solomon's era. However, the finding of an Egyptian sanctuary at the site caused various archaeologists to date the site to a few centuries earlier. Yet, recent radiocarbon analyses have shown that the main copper activity was indeed as originally proposed, and hence these are still known as King Solomon's copper mines. The science tour of Ancient Israel, which can be employed for the study of any region with a rich ancient history, shows how advanced scientific analyses of archaeological artifacts are essential for understanding the life and times of ancient societies.

Introduction

The various abbreviations used in this article, both from archaeology and science, are given with their meanings in Table 1.

Table 1. Abbreviations Used *(in Alphabetical Order)*

Used in Archaeology:	
BCE	Before the Common Era
BP	Before Present
CE	Common Era
cent./cents.	century/centuries
Used in Scientific Analyses:	
AA	Amino Acid analysis
AAS	Atomic Absorption Spectroscopy
aDNA	Ancient DNA analysis
AMS	Accelerated Mass Spectrometry
EDXRF	Energy Dispersive X-Ray Fluorescence spectroscopy
EMPA	Electron Microprobe Analysis
FTIR	Fourier Transform Infrared spectroscopy (or spectrometry)
HEC	Hygric Expansion Coefficient measurements
HPLC	High-Performance Liquid Chromatography
NMR	Nuclear Magnetic Resonance
PDA	Photo-Diode Array detector
PIXE	Particle- (or Proton-) Induced X-ray Emission
SEM	Scanning Electron Microscopy
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

This paper will discuss some of the advanced scientific analyses performed on archaeological artifacts excavated from the area ascribed to "Ancient Israel". It is difficult to delineate the borders of this ancient land as its borders shifted with various political waves over several thousands of years. Various maps show the shifting borders of this land from the time of King David and his son, King Solomon, three millennia ago, which according to various biblical scholars and cartographers consisted of the greatest land mass (*1*). These borders were reduced throughout history to present day Israel, whose international borders have still not been finalized. The archaeological term of "Ancient Israel" is used to represent the areas encompassing the modern day State as well as its environs, in what some also refer to as the "Holy Land", and has been used in other publications (*2*, *3*).

With its vast ancient history, Israel, from north to south, can be considered as one large archaeological site. In this paper we will take a tour to various important archaeological sites with an emphasis on the scientific analyses that have been performed on various objects that were found there. These sites span various epochs over thousands of years. This article is not an encyclopedic treatise on the subject, and various tomes have been published on the archaeology of this area (*4–7*). It is difficult to choose which archaeological sites in Israel to highlight, and though the land area is relatively small, yet there are over 50 major archaeological sites and a list from A to Z is available (*8*). The emphasis of this paper, though, is to single out a few of these sites, which I consider to be representative of many of the other sites, and provide examples of how and why different scientific methods were used for such analyses. The sites and cities mentioned in this article are shown in Figure 1.

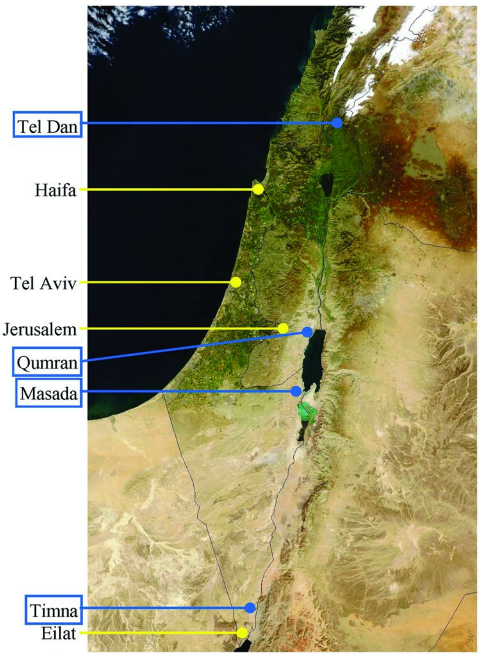

Figure 1. Satellite map showing the locations of some of the places mentioned in the paper. The four archaeological sites of Tel Dan, Qumran, Masada, and Timna are shown with a text box border. (image adapted from NASA Visible Earth, Wikimedia Commons).

The advanced scientific analyses performed on archaeological objects found in Ancient Israel go in tandem with modern cutting-edge breakthroughs that have been made in science and technology as exhibited by the eight Israeli Nobel Prize winners in chemistry and economic sciences since 2002 (*9*). Prof. Daniel Kahneman (b. 1934), an Israeli-American research psychologist at Princeton University and with academic roots at the Hebrew University in Jerusalem, was a co-recipient of the Nobel Memorial Prize in Economics in 2002 for his mathematical development of "prospect theory", a behavioral economic theory based on the psychology of judgment and decision making. The second Nobel Prize in Economics awarded to an Israeli was given in 2005 to Prof. Robert Auman (b. 1930), a co-recipient, for his mathematical development of the correlated equilibrium concept associated with conflict and cooperation through game-theory analysis.

In the chemical sciences, six Israelis were awarded the Nobel Memorial Prize in Chemistry. Prof. Avram Hershko (b. 1937) and Prof. Aaron Ciechanover (b. 1947), both from The Technion – Israel Institute of Technology in Haifa, were co-recipients of the Nobel Prize in 2004 for their discovery of the ubiquitin-proteasome pathway of protein-degradation leading to various diseases. Prof. Ada E. Yonath (b. 1939), working at the Weizmann Institute of Science in Rehovot, received her share of the prize in 2009 for her studies on the crystalline structure and function of the ribosome, and in so doing made a bit of history: She is the first Israeli woman to win the Nobel Prize and the first woman from the Middle East to win a Nobel prize in the sciences, as well as being the first woman in 45 years to win the Nobel Prize in Chemistry. In 2011, Prof. Dan Shechtman (b. 1941) of the Technion received his prize for discovery of quasi-periodicity in crystals, though two-time Nobel Prize winner, Linus Pauling (1901-1994) completely opposed that revolutionary concept. The most recent Nobel laureates are Prof. Arieh Warshel (b. 1940) of the University of Southern California and Prof. Michael Levitt (b. 1947) of Stanford University, who in 2013 shared the prize for the development of multiscale models for complex chemical systems.

Advanced scientific techniques, comparable to Nobel-type breakthroughs, were also used for the study of ancient societies from this part of the world. We will travel back in time to historical moments that not only had local importance but also helped shape world history. All this immense human achievement was recorded over a relatively short geographical distance from almost northernmost Israel to nearly its southernmost point, spanning only about 450 km, less distance than travelling from Boston to Philadelphia in the eastern USA. So fasten your safety belts as we travel on this journey along Israel's spine from the Tel of the Tribe of Dan in the north to King Solomon's copper mines in the Timna Valley in the south. We will make two important stops along Israel's mid-section in the Judean Desert's Dead Sea and visit the Qumran caves where the famous scrolls were found as well as climbing to the mountaintop of King Herod's Masada as invited guests.

The scientific tour of Ancient Israel begins now.

The Biblical Tel of the Tribe of Dan

GPS coordinates:
N33.2490, E35.6520

Web sites:
Israel Nature and Parks Authority:
http://old.parks.org.il/BuildaGate5/general2/data_card.php?Cat=~25~~970478950~Card12~&ru=&SiteName=parks&Clt=&Bur=557477527

Tel Dan Excavations:
http://teldan.wordpress.com

The biblical archaeological site of Tel Dan, the capital of the ancient northern Kingdom of Israel, is situated in the middle of the 120-acre Tel Dan Nature Reserve, a natural wonderland of streams flowing into a wild Dan River, which is the largest source of the Jordan. In the reserve are various species of trees, such as, laurel, Italian buckthorn, and Syrian ash, as well as shady hiking trails including a wheelchair-accessible trail. Nearby is Bet Ussishkin, the regional museum of nature and archaeology.

For first-time guests on an archaeological tour, a "tel" (also spelled as "tell") is an archaeological city mound formed when a new city is built on top of a much older one with a resulting rise in the city's level. Our first such area to visit will be Tel Dan, and it is an excellent example of how chemical analyses of archaeological objects found at a site can open a historical window to reconstruct the socio-economic living conditions of an ancient community. But first, a brief background on this historically important biblical and pre-biblical city.

The major excavations at this site began in the mid-1960s by Israeli archaeologist Prof. Avraham Biran (1909-2008), and a number of books have been published on these expeditions by the Jerusalem-based Nelson Glueck School of Biblical Archaeology at the Hebrew Union College – Jewish Institute of Religion (*10*). The ancient city of Dan, named after its biblical inhabitants, the Tribe of Dan, is situated in the Galilee panhandle and is one of the northernmost of cities of modern Israel. The place is mentioned several times in the Bible as also the northern border of the ancient Kingdom of Israel. Prior to it being a biblical settlement, there is archaeological evidence that this city was inhabited as far back as during the Neolithic and Chalcolithic periods of the 6th to 4th millennia BCE (*11*). Egyptian execration texts, which list troublesome neighboring states and symbolically put a curse on them, as well as cuneiform tablets from the Mesopotamian city of Mari, both attest to Dan's significance in the early second millennium BCE (*10*, *11*). Throughout the Iron Age, Israelites, Aramaeans, and Assyrians vied for control of this city whose cultic and political significance also spanned the Greco-Roman, Medieval and Ottoman periods (*10*, *11*).

There has been a number of important archaeological finds from Tel Dan (*10*, *11*), and one of them is the world's oldest known gated archway from the Bronze Age – a triple-arched mud brick gate, more than 1500 years before the Romans were to develop their arch. Also discovered are massive Early Bronze Age stone fortifications and even more imposing mud brick structures from the Middle Bronze Age. Additionally, a temple complex was found that pre-dates the Israelite period, but was probably also used from the late 10th cent. BCE by King Jeroboam. This is the monarch, as the Hebrew Bible relates, who seceded from the Kingdom of Judah and established his own break-away temple to challenge the Temple in Jerusalem for religious supremacy.

With all these discoveries, there are still two more that have major historical significance. One of the most important finds from Tel Dan is shown in Figure 2, and it is a basalt stone with a late 9th century BCE inscription written in Aramaic, a close relative to – and used the same alphabetic script as – ancient Hebrew. The writing on the stele bears a victory text in which an Aramean king claims to have killed the kings of ancient Israel, which was at the time split into two kingdoms – Judah and Israel, as mentioned above. In the existing inscription, the words "King of Israel" appear, and even more importantly, the dynastic Kingdom of Judah, which originated with King David, is mentioned with the words "House of David" (*10*, *11*), which are highlighted in the figure. This is an amazing historically important object as it is the oldest mention of the Kingdom of David outside of the Bible.

Another important object was found beneath a four-horned stone altar in the temple complex. This find was reported to be a bronze and silver scepter head (*12*), and is shown in Figure 3. However, it is not known if it belonged to a king or priest, and whether its location underneath the altar was deliberate in order to hide it or part of a cultic ritual. The top of the beautiful scepter head resembles a miniaturized altar and contains horns at the four corners, paralleling the four corner horns typically present in altars from other Iron Age sites in Israel.

The scepter head is an example of other metallic cultural material objects found throughout Israel as well as at this site (*13–15*). We shall return to this scepter head at the end of this section, but first we will discuss the metallographic and chemical aspects associated with the archaeo-metallurgical objects found at Tel Dan.

Metallurgical industrial remains dating to the 12th–11th cents. BCE were excavated at Tel Dan (*13–15*). These included tuyères (clay pipes for directing streams of air to increase the oven fire's temperature), crucibles, slags, ash pit, intact metal tools and objects (such as a pin, needle, hook, and arrowheads), and numerous metal pieces found in and around an open air metal workshop. Also included in the metallic finds are sharp "points", which could have been awls, drills, picks, or spearheads. The archaeo-metallurgist Prof. Sariel Shalev performed compositional and metallographic studies on these objects in order to understand the nature of this activity in the Iron Age I society of Tel Dan (*15*).

The chemical composition of various slag pieces and metal samples were analyzed via Atomic Absorption Spectrometry (AAS) in Israel at the Institute of Archaeology at Tel Aviv University, and by means of Electron Microprobe Analysis (EMPA) in England at the Department of Materials at Oxford University.

From the analyses of 18 elements and oxides and the degree of corrosion that the metal objects exhibit, a good picture of the metallurgical activity at this Tel Dan site can be obtained. The analyzed slags represent mainly a bronze-working industry with copper and a variable – uncontrolled – relatively low quantity of tin in the alloy, not an uncommon chemical composition of metals from other Iron I sites of the eastern Mediterranean (*15*).

According to Shalev (*15*), the results of the chemical and metallographic analyses indicate that the activity at the bronze-producing workshop at Tel Dan at the beginning of the Iron Age consisted mainly of melting/remelting processes as opposed to the first stages of metal production – smelting and refining. This is reflected by a number of factors: the presence of numerous broken bronze items near the crucibles; their tin content as compared to that in the slags; the varying and relatively low content of tin. The latter observation indicates that the Tel Dan bronzesmiths did not control the quantity of tin in the melt and thus did not obtain an optimal amount of tin in their bronzes. This is also indicative of the metal workers not adding tin, but rather using whatever tin was already present in the metal scraps.

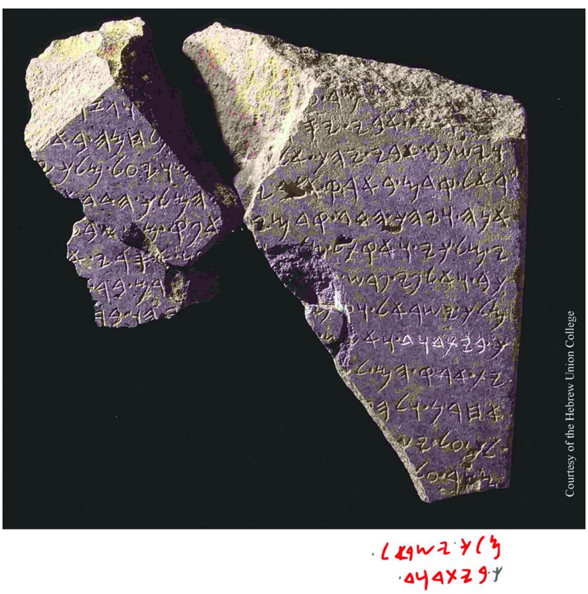

Figure 2. (Top) Tel Dan stele consisting of joined fragments with Aramaic inscriptions including mention of the "King of Israel" and "House of David"; the latter is highlighted with the added white markings (image courtesy of the Hebrew Union College). (Bottom) A drawing of part of the 8th and 9th lines of the stele inscription (adapted from the drawing by Schreiber, Wikimedia Commons), showing the following words highlighted in red: 8th line (from right to left): MLK YSREL ("King of Israel"). 9th line (from right to left, after the first dot): BYT DVD ("House of David").

Figure 3. Bronze scepter head found underneath a stone altar at Tel Dan. (image courtesy of the Hebrew Union College).

Thus, these analytical results can reflect upon the socio-economic conditions of the population living in Tel Dan during the Iron Age of the end of the 2nd millennium BCE (*15*). Shalev reports that the bronze-manufacturing process practiced at Tel Dan was not a sophisticated and complex industry, but rather consisted of a simple local industry that basically met the needs of the immediate population in domestic tools and in weapon accessories. The smiths recycled broken and defective scrap bronze pieces to produce their new wares. All aspects of the analyses lead to the conclusion that this was a simple population needing simple objects made from scrap materials.

We now return to that beautiful bronze scepter head, which by its very material character, I propose also depicts a simple way of life presented by the people of this settlement. The kings and priests of many cultures possessed scepters made of precious gold, which has so far not been found at this site. The fact that such a sacred or royal (or both) important object is composed of mainly bronze shows again that these people did not possess great material wealth, but could only afford to fashion their ritual objects from bronze. This bronze scepter head could have certainly been produced in the local metal-working workshop, but is awaiting further chemical analyses before a final judgment is declared on that object.

We now leave the relatively green Galilee landscape and travel 200 km due south to the arid land of the Dead Sea to visit the next archaeological site and understand the scientific analyses on the objects that were found there.

Qumran and Dead Sea Scrolls Science

GPS coordinates:
N31.7412, E35.4591

Web sites:
Israel Nature and Parks Authority:
http://old.parks.org.il/BuildaGate5/general2/data_card.php?Cat=~25~~882773155~Card12~&ru=&SiteName=parks&Clt=&Bur=557477527

Israel Museum Shrine of the Book, Jerusalem:
http://www.english.imjnet.org.il/page_899

The Qumran National Park, overlooking the northwestern shore of the Dead Sea, includes a Visitors Center that is designed like Qumran's ancient buildings and shows a dramatic audiovisual presentation of the site where many of the "Dead Sea Scrolls" were found. The ruins include a dining hall, ritual bath, and other finds that recall the living habits of the people whose separatist ascetic nature led them to the desert in search of ritual purity. From the site of the ruins there are breathtaking views of the caves in the curvaceous mountainous area. The trail through the ruins is wheelchair-accessible, and there are also special signs for the visually impaired. Some of the more important scrolls are exhibited in the Shrine of the Book at the Israel Museum in Jerusalem.

The Dead Sea

There is probably no other archaeological area anywhere in the world on which so much has been written than the Dead Sea and on the main artifacts found there, known cumulatively as the Dead Sea scrolls. The term "Dead Sea scrolls" has been applied not only to the parchments and papyri that were found in the caves in Qumran (also spelled Kumran), but also to all the writings discovered in neighboring sites in the Judean Desert (see Figure 4).

The body of water known as the "Dead Sea" has been misnamed – it is neither "dead" nor a "sea" – but this name has been used in the English language, though the Hebrew name for this body of water is known as the "Salt Sea" – a better name. The Dead Sea itself is about 400 m below sea level, the lowest point on earth, which produced the world's highest recorded barometric pressure at about 800 mm Hg (*16*). It is also the most saline of any body of water with about 350 g total salt/L, which is incredibly about 10 times that of the oceans, and is thus devoid of most sea life (*16*). This high buoyancy makes it easy to float in the Dead Sea, which anyone who has visited the area knows very well.

The climate of the Dead Sea area can be inhospitable to humans who have not prepared themselves for the science tour, especially in the summertime, due to its extremely dry, hot climate, coupled with strong solar radiation. Summertime temperatures can easily climb well into the high 40s (degrees Celsius) – high enough to boil some organic solvents, such as, diethyl ether, dichloromethane, and pentane, and of course can easily melt the francium (Fr), cesium (Cs), and gallium (Ga) metals to liquid.

Though the Dead Sea area is deprived of much natural vegetation, this body of water is very much alive with archaeological and mineral treasures, and has been one of the most intellectually fruitful of areas for mankind. Though the artifacts from this area, which is geographically situated in the eastern part of the world known as the Near East or modern Middle East, it has been of vital importance to western civilization.

Figure 4. Qumran caves in the Dead Sea area. (© Zvi C. Koren).

Dead Sea Scrolls – General Discussion

Much has already been written on these scrolls and about the makeup of the population of the Jewish sect inhabiting this area, and there are even two different publication series on this topic: Discoveries in the Judaean Desert (DJD) published by Oxford University Press (*17*) and Dead Sea Discoveries (DSD) published by Brill (*18*), each dedicated to the scrolls and related artifacts. Much current information about the scrolls is available at the scrolls digitization project of the Israel Antiquities Authority (*19*). One of the scientists who has published extensively on the analyses of these scrolls is Dr. Ira Rabin of the BAM Federal Institute for Materials Research and Testing in Berlin, and some of her recent publications are listed in the references (*20–26*).

The legendary story of the discovery of the Dead Sea scrolls is well-known (*19*), and as the anecdote is told, in 1947, a young Bedouin shepherd stumbled upon the scrolls in caves while looking for a lost goat or sheep. Originally, seven scrolls were found, but between 1947–1956 tens of thousands of fragments, mostly parchments and some papyri, from perhaps hundreds of documents were found in

Qumran and neighboring areas of the Judean Desert. Some of the scrolls that were wrapped in linen were found in closed clay jars, while others were not. Other scrolls were found in broken or open jars, and yet others were discovered on the cave floors, in niches in cave walls, and also buried in the earth of the cave floor. It is then no wonder that environmental conditions to which the scrolls fragments were exposed for about 2,000 years resulted in degradation of many of the scrolls. One exceptional scroll was written on a sheet of copper, and is known as the "copper scroll".

The writings of the scrolls consist of biblical and non-biblical or sectarian communal rules to be followed in order to adhere to a unified community. The scroll collection consists of partial or complete copies of every book in the Hebrew Bible, except the Book of Esther, which describes the events occurring outside of Israel (ancient Persia). Most of the Hebrew Scrolls are written in the standard "square" (or "Jewish") script, very similar to today's Modern Hebrew that can be read even by a child. One of the more famous of such scrolls is the one containing the "Ten Commandments", which are written twice in the Hebrew Bible (Exodus 20 and Deuteronomy 5), and is shown in Figure 5. Other scrolls are written in paleo-Hebrew, an ancient script of the First Temple era, and a few were written in Aramaic and Greek.

The scientific aspects related to these scrolls will now be discussed.

The Age of the Scrolls

Based on the writing styles (paleography) of the manuscripts, experts in that field have dated the oldest scrolls to the mid-3rd cent. BCE and the youngest to 68 CE, when the Qumran community was destroyed by the Romans (*19*). However, arguments began surfacing regarding the validity of dating of the scrolls based on paleography alone, and so, to rectify this situation, scientific tests were also performed.

Radiocarbon dating analyses on the scrolls themselves were published only in 1992 (*27*) and later in 1995 (*28*). Previous to the 1992 paper, only related items were analyzed via radiocarbon tests. The first radiocarbon test on a sample from one of the Qumran caves was performed in 1950 by the 1960 Nobel Laureate in Chemistry, Willard Libby (1908–1980), who developed the Carbon-14 dating method at about the same time that the scrolls were discovered. In the original method, large quantities (several grams) of samples were needed for the destructive test, and hence the scrolls themselves were not analyzed at the time. Libby analyzed a linen sample from one of the caves and found the date of the textile to be 1917 ± 200 BP (Before Present, the conventional way that radiocarbon years are presented), that is about 2,000 years old.

One of the major problems associated with C-14 tests on any organic sample is in the handling and treatment of the artifact after it has been removed from its archaeological location (*29*). Some of the scrolls underwent treatment with organic oils, such as castor oil, in order to improve the visibility of the writings, or with rice paper and glue, which were used in the conservation/preservation stage. Hence, radiocarbon dating analyses could lead to younger dates due to the application of these modern materials.

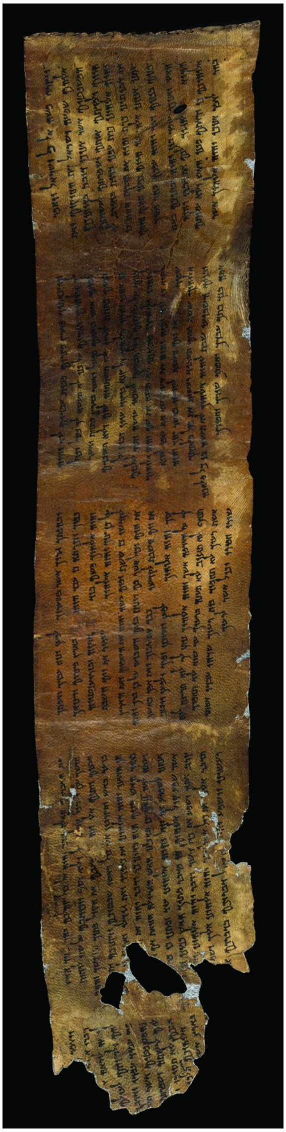

Figure 5. Dead Sea scroll parchment with the Ten Commandments. Manuscript ID: 4Q41 – 4Q Deut^{n}; Plate 981, Frag 2, B-314643; website: http://www.deadseascrolls.org.il/explore-the-archive/image/B-314643. (photo by Shai Halevi, full spectrum color image, courtesy of the Israel Antiquities Authority).

The first published radiocarbon dating of the scroll was performed at the ETH-Zürich Institute for Medium Energy Physics, and was reported in 1992 (*27*). In that report, analyses on eight Qumran scrolls were performed via AMS (Accelerated Mass Spectrometry). The oldest scroll that they dated was from 309–235 BCE, and the youngest was 21 BCE – 61 CE. The correlation between the radiocarbon and paleographic dates was reported as good. The radiocarbon dates were older than the paleographic ones, which is logical due to the fact that the writing occurred after the parchment was prepared. Assuming that the space of time between producing the parchment from animal skins and the date at which the writing occurred was relatively short, the calibrated C-14 ages of the scrolls were then a logical, on average, 35 years older.

A few years later, C-14 results on 15 Qumran scrolls were performed at the NSF Arizona Accelerator Mass Spectrometer Facility at the University of Arizona in Tucson, and published in 1995 (*28*). Their published results show that paleographic dating based on the scribal style of writing usually matches the scientific testing. The oldest dated scroll that they measured was from 272 ± 101 BCE, while the youngest scroll date had a calibrated age of 182 ± 48 CE.

Animal Sources of the Parchments

According to Jewish law, *Halakhah*, a parchment for the writing of sacred texts may only originate from the hides of a kosher animal, such as a cow, sheep, or goat. The evidence to date regarding which animals were used for the production of the parchments is not decisive. The earliest determination was in 1958 when Dr. Michael L. Ryder, a British expert in the history of sheep and analysis of wool fibers (*30*, *31*) analyzed specimens of eighteen scroll fragments to aid his work on the evolution of the domestic sheep. He determined that both goat and sheep skins were used for the parchments, although a calf-skin was also used. Additional analyses also determined that goat and sheep skins were used as well as and one calf skin fragment (*32*, *33*).

However, it was believed that there was a wider range of species used for parchment production due to the physical variations of texture, color, thickness, and follicle number and distribution in the surviving parchments (*34*). Additionally, it was claimed that the exact species identification is impossible using Ryder's microscope-based technique (*34*).

Ancient DNA (aDNA) work was begun in the mid-1990s (*34*) and continued thereafter (*35*) in order to determine the source of the animal skins used for the parchments. In the first study, eleven scrolls were analyzed by extracting aDNA from small portions of parchment fragments of the Dead Sea Scrolls with the aim of identifying unique genetic signatures of the fragments. The study found the use of goat skins, but also of gazelle or ibex. However, this investigation disagreed with Ryder in that they did not find the use of sheep skins for the parchments. In the latter study (*35*), mostly domestic goat skins were found to be used as well as some local Nubian ibex.

More research in this area is needed in order to produce indisputable proof as to which animals were used for the parchments.

The Black Ink on the Scrolls

The color of the ink used in practically all the scrolls is black (see Figure 5, for example), as is obvious and to be expected, but there are four scrolls where a red ink was used for some of the writing, and the chemical composition of this red ink will be discussed in the next section.

The two types of black ink that was typically available in the ancient world are succinctly referred to as "carbon-black" and "iron-tannate". The carbon-based ink was produced from ground charcoal, soot, or lampblack. The iron-based ink was an insoluble pigment formed from the reaction between an iron salt and various tannins available from oak galls or gall nuts.

The first study that attempted to determine the chemical composition of the inks used in the Dead Sea scrolls was begun in the 1950s, but a detailed scientific report on it was not published. In 1955, Dr. Harold James Plenderleith (1898-1997), a Scottish art conservator, archaeologist, and chemist, and formerly Keeper of the Research Laboratory of the British Museum, studied the conservation treatments needed in order to preserve the scrolls (*36*). Plenderleith noted that in his tests, he treated the scrolls with water and a mild bleaching agent and while some of the dark contaminants on the scrolls did clear up, these treatments had no effect on the ink. From these observations and from his microchemical tests on the inks, he concluded that the black ink on the scrolls that he investigated did not contain iron.

Steckholl (*37*) gave more details concerning Plenderleith's analyses and he reported that twelve separate fragments with residual ink were tested with potassium ferricyanide in the classic wet chemical analysis for the detection of iron. In the case of the inks from these Dead Sea scrolls, no iron was detected. Further, as reported by Steckholl, "the ink was quite black and showed no tendency to turn rust colored." Additionally, bleaching agents had no visual effect on the intensity of the ink. Steckholl agrees with Plenderleith's conclusion that the black ink is not iron-based, but rather carbonaceous. Steckholl continued his report by noting that Plenderleith used a spectrograph to examine an ink sample whose main component was carbon and calcium and also contained traces of copper, tin, lead, silver, iron, and manganese. Steckholl surmised that these trace metals in the ink sample indicated that the original ink was contaminated by the metals leaching out of a bronze inkwell. Such a small container was found at Qumran by Father Roland de Vaux (1903-1971) of the École Biblique of Jerusalem who was digging there between 1951–1956 (*38*). Finally, Steckholl reports on another ink residue found in a clay inkwell that was tested by Dr. George Adler of the Brookhaven National Laboratories in New York with the result that the sample did not contain an appreciable amount of iron since it did not fluoresce when tested with a copper X-ray tube. Hence XRF (X-Ray Fluorescence) also confirmed that of all the inks examined, none pointed to an iron-based compound.

More analyses of the inks were performed in the mid-1980s at the Crocker Nuclear Laboratory at the University of California, Davis, using PIXE, particle- (or proton-) induced X-ray emission. Though it was unpublished, nevertheless, it was reported on by the Israeli researchers Dr. Yoram Nir-El and Dr. Magen

Broshi, formerly of the Soreq Nuclear Research Center in Yavne and of the Shrine of the Book at the Israel Museum in Jerusalem, respectively (*39*). This elemental analysis technique did not detect any appreciable quantities of metallic elements, though in some samples traces of copper were detected, usually with traces of lead. Hence, since the chemical composition of the black ink could not be ascribed to a metallic content in it – specifically iron – it was thus concluded, once again, that the nature of the ink is carbon- and organic-based, which PIXE could not detect.

Dr. William S. Ginell (*40*), working at the Getty Conservation Institute, led a team that performed certain analyses on the Dead Sea scrolls and published a lengthy report on the findings in 1993. The methodologies that he and others used included FT infrared spectroscopy, nuclear magnetic resonance spectroscopy, x-ray fluorescence analysis, amino acid analysis, chromatography and hygric deformation methods. His main mission was to study the degree of degradation of the Dead Sea scrolls and also to determine the optimum environmental conditions (such as, relative humidity and temperature) required for storage and display of the scroll fragments.

Infrared spectroscopy could not detect the presence of organic tanning agents, if present. Ginell also utilized XRF in order to analyze the black ink on a badly deteriorated fragment of the Genesis Apocryphon scroll. This is a unique scroll written in Aramaic on four sheets of leather, whose extra-biblical narrative describes a mythical conversation between Methuselah's son Lamech and his son Noah. The parchment shows severe degradation in certain parts along the inked writing where elongated voids were thus formed. Ginell also analyzed parchment samples from other Qumran scrolls. In all these cases, he did not find any difference between the iron-content in the area with ink and in the blank unwritten part of the parchment. Hence, according to Ginell too, iron-based ink was not used in these writings.

Ginell notes that two other scrolls (identified by their manuscript IDs as 4Q115 Daniel D and 4Q270 Daniel E) exhibit the same type of inscriptional degradation as does the Genesis Apocryphon. All three scrolls were written in Aramaic whereas all the others that he analyzed were in Hebrew. He conjectures that the scribes who wrote these documents originated from the same area where the ink ingredients were similar or identical and different from the other inks. It is very likely that the inks used in Aramaic scrolls were different from most of the other inks, which are carbonaceous-based. He also indicates that the deterioration of the parchment around the inked areas was accelerated by the high moisture content resulting from opening of the parchment and storing it in an environment with a relatively high relative humidity. However, Ginell does not provide any explanation of why specifically the Genesis Apocryphon scroll shows inscription degradation much more than the other scrolls that shared the same environmental fate over two thousand years of time.

In 1996, Nir-El and Broshi published the results of their own XRF examinations of the black ink on three papyrus fragments (*39*). Their results agreed with Ginell's in that they found no difference between the relative iron content in the inked and non-inked areas of the samples. They also measured the relative content of other elements in the ink, including sulfur (S), chlorine (Cl), potassium (K), titanium (Ti), chromium (Cr), manganese (Mn), nickel (Ni), zinc

(Zn), bromine (Br), and strontium (Sr), and found no appreciable levels of these elements in the ink, and thus the composition of the ink cannot be based on them. However, Nir-El and Broshi's results on the relative copper and lead content in the inked region showed that these metals were about 3–4 times more abundant in the inked regions than in the blank parts of the papyri. However, they surmise that this abundance was not observed in the measurements that were performed on other Qumran scrolls, and thus the black ink is not due to the presence of these two metals. These two elements were nevertheless only trace quantities in the ink. Rather, their presence would seem to be an artifact – an accidental or non-deliberate inclusion of these elements in the ink. They posit, as did Steckholl, that these elements could have leached into the ink from the use of a bronze inkwell. To corroborate their claim, they note that ancient bronzes contain, by weight, approximately 75% Cu, 20% Pb, and 5% Sn, relative percentages that they claim were found in their ink analyses.

Nir-El and Broshi also analyzed parchment samples from other scrolls including the famous Genesis Apocryphon. In all these cases, as in the papyri fragments, there was no uniformly excessive iron in the ink relative to the non-inscribed areas, and thus, once again, these analyses show that the ink was not iron-based, but composed of a carbonaceous pigment. Though in all papyri and parchment samples examined the iron content was relatively high, the authors assume that this metal is not from the natural presence of iron in the animal skin or from the use of the Dead Sea water used in the processing of the hides, which in both cases have very low iron content. They presume that in antiquity pumice stone, which according to their EDXRF analyses contains high iron content, was used as an abrasive to prepare the substrates for writing by first smoothing the papyri or parchment by rubbing. They also contended that they detected rubidium in the parchment and papyrus fragments, which is an element present in pumice stone but not in Dead Sea water.

Though they did find considerably higher values of copper and lead in several deteriorated parchment samples, especially in the Genesis Apocryphon, they nevertheless still attribute the presence of these metals to leaching from a bronze inkwell, and here too they conclude that the ink is carbonaceous in nature.

Nir-El and Broshi theorized that the reason the parchment with the inked area degraded in some of the writings of the Genesis Apocryphon is not due to the ink itself but to the binder. The binding material was not analyzed by the authors, but they assume that it could have been vegetable gum, animal size, oil, honey, or others. These materials, according to the authors, can cause the chemical and physical degradation of the parchment regions where ink was applied. This degradation could have been aided by certain environmental factors such as humidity, temperature, light, oxygen, air pollutants, insects, and animals. Additionally, the salts that are present in the parchment from the processing of the animal skins to parchment are hygroscopic and an increase in the water content can cause the denaturation of the collagen in the parchment to gelatin, and would also create mechanical problems – stress and elongation – in the parchment leading to the flaking of the ink layer.

Nir-El and Broshi's claim that the binding material used in the ink for the Genesis Apocryphon is different from – and more detrimental to – the parchment, than the binders used in the ink in all the other scrolls has not been laboratory tested. Though they insist that the ink used in the Genesis Apocryphon is the same carbon-based type as used in all the other scrolls, they do indicate that there is a minor role that the copper and lead ions present in the Genesis ink may play. They conjecture that the metals' chemical action on collagen can cause the deterioration of the collagen where the ink has been used.

I propose that it is possible that the ink that was used in the Genesis Apocryphon scroll is different from the other inks. Based on the publications by Ginell and also by Nir-El and Broshi, which report that the copper content was indeed higher in the Genesis Apocryphon ink than in the others, then that determination adds more weight to the thesis that a copper-based ink was in fact used. Consequently, as inferred by Nir-El and Broshi, the copper may be instrumental in degrading the collagen of the parchment. It is known that copper ions facilitate the decarboxylation of RCOO– groups in proteins and thus cause the deterioration of the proteinaceous material (*41*).

The Talmud may have referred to such a copper-based ink as the Mishnah of the Babylonian Talmud (Gittin Ch. 2, Shabbat Ch. 12, Sotah Ch. 2, Megilah Ch. 2) and the Mishnah of the Jerusalem Talmud (Megilah Ch. 2, Shabbat Ch. 12) mention an ink by the name of *kankanthom* or *kankanthum*, whose meaning is shoemaker's black pigment (*charta de'ushkafei* in Aramaic). That is, this was originally a black pigment for coloring leather. A variant Talmudic spelling is also given in the Mishnah of the Jerusalem Talmud (Gittin, Ch. 2; Sotah, Ch. 2) as *kalkanthos*. These words are linguistic modifications of the Greek *χάλκανθον (chalkanthon)* and *χάλκανοζ (chalkanthos)*, respectively. These terms probably refer to cupric sulfate since the dictionary definition of these equivalent compounded Greek words derives from *χαλκό* (copper) and *άνθοζ* (flower) (*42*). This "copper flowers" compound has produced the following etymological variants, such as, *cupri rosa*, *cuprosa*, etc., which has evolved into the modern word "copperas" (*43*, *44*). Though, in modern times copperas is used to denote iron sulfate – or green vitriol – in its original context it was associated with the soluble sulfate of copper (blue vitriol), though there was probably some iron impurity mixed with it (*45*).

The mention of the ink known as *kankanthom* or *kalkanthos* in the Mishnah, which was compiled over the first two centuries of this era, indicates that this type of ink must have been known to the Jerusalem or Qumran scribes by the 2nd cent. CE. Further, the Roman historian Pliny the Elder (23–79 CE), in his treatise on Natural History (*46*), also mentions (in Book 34, Ch. 32) shoemaker's black pigment known as *chalcanthum* produced from dissolved copper found in well water in Spain. Additionally, Pliny's 1st cent. CE contemporary, Dioscorides (40–90 CE), the Roman physician, pharmacologist, and botanist of Greek origin, who wrote a treatise on herbal medicines and related medicinal substances (*47*), also mentioned this colorant. In Book 5, Ch. 114, of his work he refers to a blue compound called *χαλκανθον (chalkanthon)* that produced a black dye, and in the last chapter (Ch. 138) of Book 5, after he mentions a black ink produced from soot, he then goes on to describe a medicinal concoction that includes *chalcanthum*.

Hence a copper-based pigment was already well-known in the Roman Empire already by the 1st cent. CE and could have been used for the Dead Sea scroll known as the Genesis Apocryphon. Finally, with regard to this scroll, it is noteworthy to mention that Avigad and Yadin, who were the first to publish the contents of the Genesis Apocryphon in 1956, commented on the decomposition of the ink, and that it was different from the ink used in other scrolls (*48*). However, they never had the Genesis ink analyzed.

In summation of this section, in spite of the various errors appearing in the literature – both in the print and electronic media – most of the black inks used in the Dead Sea scrolls were carbonaceous-based (from soot, lampblack, charcoal, etc.) and were not composed of iron-tannate.

Rare Red Ink in the Scrolls

A most unusual find was that out of the thousands of Dead Sea scroll fragments, four pieces contained lines written with red ink, and two such examples are given in Figure 6. The red ink on all four fragments was analyzed by Nir-El and Broshi by means of two related techniques, XRF and XRD (*49*).

The results clearly showed the preponderance of mercury in the red inscription area, and of all the red mercury compounds, mercuric sulfide, HgS (known as cinnabar or vermilion) is the most abundant natural mineral. According to the authors, the use of a red ink pigment as found in the Dead Sea scrolls is more than a thousand years older than the previously known example of cinnabar as an ink. It is well-known that this artists' pigment was used with other such colorants in Byzantine and Medieval manuscripts (*50*). The two-thousand year old mystery, though, still remains: Why did the scribe or scribes find it necessary to use red ink in a few rare instances.

An attempt to track down the geographical source of this pigment requires an international travel package together with geo-chemical detective work. According to geochemists Dr. Naomi Porat and Dr. Shimon Ilani, working at the Geological Survey of Israel in Jerusalem, cinnabar ores have not been discovered in Israel or in its neighboring regions (*51*, *52*). Thus, this pigment was exported into this region, but from where? The two other cases where cinnabar was detected from Ancient Israel was in the palaces of King Herod (73–4 BCE) at Masada and Jericho (*53*, *54*), and in both cases as a paint pigment for wall paintings, and not as an ink for writing manuscripts (*51*, *52*). At Jericho, not only was cinnabar detected on wall paintings, but it and other pigments were individually placed in their native state in artists' bowls ready to be applied to the walls (*51*, *52*).

The source of the cinnabar in King Herod's palaces can be determined from his political background. This ruler, known as King Herod of the Jews, was a Rome-appointed king of Judea, and his style of living and artistic preferences would be that of Rome. Cinnabar was well-known in the Roman world (*55*), and the typically bold red color used in Roman-period wall paintings is cinnabar. Both the 1st century BCE Roman-period sites of Masada and Jericho are in relatively close geographic proximity and contemporaneous with the Qumran scrolls period; thus, all these sites would have shared the same materials. Whatever was available in Rome was eventually transported into Ancient Israel by the Roman artisans. According to the afore-mentioned 1st cent. CE Pliny's Natural History (Volume

9, Book 33), the Romans imported cinnabar mostly from Spain – from the mine of Sisapo (Almaden) in the Baetic region (*46*). Nir-El and Broshi then concluded that this red pigment on the Dead Sea scrolls made its long journey from Spain to Rome to Judea.

Figure 6. Two parchment fragments with red ink; actual height sizes are about 2 cm and 7.5 cm, for top and bottom images, respectively (adapted from photos of Shai Halevi, full spectrum color images, courtesy of the Israel Antiquities Authority). (Top) Manuscript ID: 2Q15 – 2Q Job; Plate 741, Frag 26, B-366041; website: http://www.deadseascrolls.org.il/explore-the-archive/image/B-366041. (Bottom) Red ink is visible at the bottom line. Manuscript ID: 4Q27 – 4Q Num^{b}; Plate 1082, Frag 2, B-295285; website: http://www.deadseascrolls.org.il/explore-the-archive/image/B-295285.

We will now travel about 50 km south from the Qumran area, but still hugging the Dead Sea to our left, on the east, in order to reach the fabled Masada.

King Herod's Masada

GPS coordinates:
N31.3156, E35.3538)

Web sites:
Israel Nature and Parks Authority:
http://old.parks.org.il/BuildaGate5/general2/data_card.php?Cat=~25~~736559308~Card12~&ru=&SiteName=parks&Clt=&Bur=557477527

The Yigael Yadin Masada Museum:
http://old.parks.org.il/BuildaGate5/general2/data_card.php?Cat=~25~~546680273~Card12~&ru=&SiteName=parks&Clt=&Bur=765033202

The Masada National Park has been declared as a UNESCO World Heritage Site due its universal values. Masada includes the preservation of a 1st century BCE Roman-period palace built by King Herod of the Jews, and 1st century CE remains of the Roman siege structures and vestiges from the tragic struggle for freedom from Roman occupation by the Jewish rebels atop this mountaintop in ancient Judea. Based on the latter-mentioned aspirations of these inhabitants who met a catastrophic end, this mountaintop site has been dubbed as a "symbol of determination and heroism". The top of this natural plateau can be reached via three modes, whereby the easiest is by means of a cable car to near the summit. The other two means are by foot trails, the formidable "snake path" in the east and the less steep "ramp trail" approached from the city of Arad in the west. At the base of the mountain is a moving audiovisual presentation that introduces the visitor to the Masada story, as well as the Yigael Yadin Museum that exhibits various artifacts excavated at the site. From March to October, a sound and light show is presented against the dramatic backdrop of the western side of Masada.

Masada (Figure 7) is probably the most visited archaeological site in Israel outside of Jerusalem. At this mountaintop cliff overlooking the Dead Sea in the Judean Desert, King Herod built his palatial fortress in the last quarter of the 1st cent. BCE (*56*). King Herod's short-lived dynasty was to be the last monarchy of Ancient Israel. The name of this site is derived from its Hebrew name, *Metzadah*, which means fortress or fortification. Still extant are various buildings, floor mosaics, and wall paintings. One can visit this 400-meter high cliff by hiking up one of the footpaths, such as the Snake Path, or take a cable car to near the top of this cliff.

The main story of Masada consists of two periods, separated by about a century. The first Herodian period is the glorious construction of remarkable architecturally challenging edifices commissioned at this site by King Herod, and various artifacts have also been found from this period. The second period associated with Masada is the tragic one as recounted by Flavius Josephus

(37–100 CE), the Jewish-Roman historian (*57*). Josephus was originally the Jewish general Yosef ben Matityahu of the priestly and royal Hasmonean dynasty, who led the Galilee brigade fighting the "Great Revolt" against the Roman occupation of Judea in the latter half of the 1st cenury. CE. However, as he was vastly outnumbered by the Roman army, he surrendered to General (later to be Emperor) Titus Flavius Vespasian (9-79 CE), whose son Titus (39-81 CE) defeated the Jewish revolt. After being taken to Rome, he was granted Roman citizenship, and appended the name Flavius to his Romanized Hebrew name, Josephus, to honor his patron, the emperor Vespasian, founder of the Flavian dynasty. In these new Romanized surroundings, Josephus embarked on his new – and invaluable – role as historian of that period.

Figure 7. Masada – aerial picture; the three-level northern palace is shown in front; top left is the Dead Sea. (photo credit Andrew Shiva, Wikimedia Commons).

As Josephus recounts in his epic Wars of the Jews, the Herod's magnificent palatial fortress of Masada was also the setting for one of the worst tragedies befalling the struggling Jewish nation, about a century after the Herodian complex was built. Alas, Masada became the last stronghold of those Jews who rebelled against the Roman occupation of Judea. Josephus recounts the ghastly mass self-carnage that was performed by nearly one thousand men, women, and children desperately attempting to stave off the mighty Roman army. After three years of fighting, when the end was near, their leader Elazar passionately appeals to the masses atop this palace-fortress to end their lives instead of being taken in captivity with all the dire results that may befall them. According to Josephus, Elazar ends his exhortation with these words (*57*):

"Let us die before we become slaves under our enemies, and let us go out of the world, together with our children and our wives, in a state of freedom … Let us therefore make haste, and instead of affording them so much pleasure, as they hope for in getting us under their power, let us leave them an example which shall at once cause their astonishment at our death, and their admiration of our hardiness therein."

In the following chapter, Josephus continues his narrative and relates the bone-chilling events that transpired immediately after Elazar's speech, wherein the men killed their families – women and children – and then committed mass-suicide, leaving nearly a thousand dead atop the mountain. Yet, two women and five children had concealed themselves in caverns underground, and survived to tell the Masada story, which is spellbinding to this very day. Some of the personal effects found at this site are sandals, prayer phylacteries boxes with straps, comb, mirror, and even, chillingly, an intact young girl's braided hair.

The major excavations of this site were performed in the early 1960s by the dean of Israeli archaeologists, Prof. Yigael Yadin (1917–1984), together with many Israeli and international volunteers. There were so many finds from that site that to date eight detailed volumes have been published by the Israel Exploration Society in Jerusalem on the analyses of these finds and these publications are still ongoing (*58*). The second archaeologist who continued Yadin's work was Prof. Ehud Netzer (1934–2010), who unfortunately recently tragically passed away after encountering a fatal fall at another Herodian site near Jerusalem, known as Herodion, that he was excavating.

The pigments on the wall paintings of Masada (Figure 8) were analyzed by Porat and Ilani via XRD and SEM, and, not surprisingly, most were found to be identical to the ones used at Herod's other palace at Jericho (*50, 51*). The pigments identified included red (cinnabar, vermilion), orange (minium), green (celadonite), black (soot), white (chalk), pink (kaolinite), brick-red (hematite), yellow (goethite), and blue (cuprorivaite).

Among the many archaeological treasures that were excavated at Masada, perhaps none are more personal than the textiles that were also found there, most of them belonging to the Jewish rebels. These were the household furnishings used in their makeshift dwellings and garments that clothed them.

It was with this calamitous Masada background haunting me that I braced myself to actually touch those fabrics and to study them. One of the first textiles that I examined from this site was a small fragment (Figure 9) that was excavated in an area that was part of the royal refuse dump of the western administrative palace and was situated at the northeast corner of that edifice (*59*). A "throne room" was discovered in that palace in which four rectangularly arranged niches were found in the floor in a corner of this chamber (*56*). These niches were undoubtedly used for the supporting poles of a royal canopy in a room that was large enough for people to have an audience with the king. Based on the fact that this textile was found with other artifacts, which have been stylistically and archaeologically dated to the Herodian period of the 1st cent. BCE, and not to the Jewish rebels from a century later, so too was this textile dated from the Herodian period.

Figure 8. Original remnants of wall paintings at Masada. (© Zvi C. Koren).

The Herodian textile weave contained weft yarns that were entirely reddish-purple, whereas the warp yarns, consisted of plied yarns for extra strength – one red-purple and the other undyed yellowed fibers. The HPLC-PDA chromatographic and spectrometric results of my analyses of the red-purple fibers detected indigo together with related brominated indigoid components (Figure 10). The resultant HPLC chromatogram shows the three major indigoid components as well as a minor, but nevertheless significant, amount of the doubly-brominated indirubinoid. Since the latter component's absorption is at about 540 nm, the chromatogram is depicted at that wavelength for visualization purposes, and not for quantification.

The quantitative results of the chromatographic peak areas of the blue, violet, and reddish components are shown as percentages at the standard wavelength of 288 nm. These brominated indigoid components are the trademark of a pigment that can only be produced from certain sea snails (*59*). These specific mollusks are the *Muricidae* species, and the purple pigment was produced in antiquity from the substances contained in the colorless fluid of the hypobranchial gland of these *Murex* sea snails. Based on the fact that the MBI dye consisted of a relatively large quantity, the malacological provenance of this purple pigment must be from a specific species, the *Hexaplex trunculus* sea snail. This is because only that purple-producing species can yield an abundant quantity of that dye (*54*). Further, the chromatographic fingerprint of this archaeological dyeing showed a much greater amount of the dibrominated indigoid dye (DBI) than the unbrominated indigo colorant (IND) (*61*), which indicates that the *H. trunculus* sub-species that produced it was the DBI-rich variety (*62*).

The finding of a true-purple molluskan dye in a textile is highly significant. We know that this dye was used in the textiles for kings ("Royal Purple"), high priests, and in the textile furnishings of the Tabernacle in the Temple in Jerusalem. This rare molluskan pigment has also been known as "Tyrian Purple", after one of the capital cities of the sea-faring Phoenicians, the foremost traders and merchants of the ancient world, whom history has credited with perfecting the craft of purple dyeing.

Figure 9. Microscopic image of a Herodian textile fragment (maximum width of about 2 mm) found at Masada. (© Zvi C. Koren).

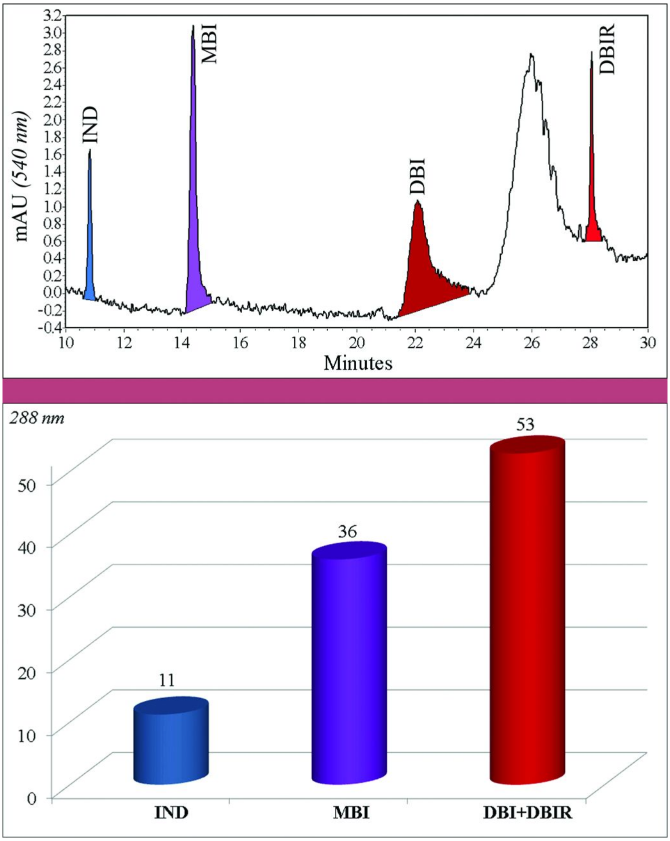

Figure 10. Qualitative and quantitative depictions of the results of the HPLC analyses of a DMSO-extract of the dye from a miniscule reddish-purple yarn excised from the Herodian weave of Figure 9. The abbreviations of the dye components are as follows: IND (indigo), MBI (6-monobromoindigo), DBI (6,6'-dibromoindigo). (Top) HPLC chromatogram shown at 540 nm for visualization purposes. (Bottom) Quantification of the chromatographic peak areas (as percentages) of the blue, violet, and reddish components calculated at the standard wavelength of 288 nm. (© Zvi C. Koren).

Based on the chemistry, malacology, history, archaeology, and religion associated with this molluskan dye, the significance of the discovery of *Murex* purple on this fabric can be highlighted as follows: (a) this was the first time that a *Murex* purple fabric from Ancient Israel has been discovered; (b) the fabric found in the Herodian layer must have belonged to King Herod himself since the dye – "Royal Purple" – was the prerogative of kings; (c) based on the physical structure of the weave, the whole fabric, and not just this small fragment, was purple-colored; (d) the type of weave of this textile is one typically found in a cloak or mantle; thus, the fragment analyzed may have been part of the royal cloak or mantle of King Herod; (e) the color of this fabric was most likely that of the *Argaman* dye, one of three biblical dyes.

Thus, one of the most important biblical treasures ever to be found, the biblical Herodian *Argaman* dyeing worn by kings and priests and unearthed at Masada, established the true color of this biblical dye. One key to the puzzle of the trilogy of sacral colors was now deciphered.

Recently, I have chemically discovered another historically and biblically important textile from Masada, and it was a very small embroidery consisting of bluish-purple (dark violet) yarns on an undyed textile. Analysis of this textile proved that its origin was also from a *H. trunculus* snail due to its appreciable MBI content. However, it came from an IND-rich snail that possessed higher IND than DBI. This then was the other biblical dye known as *Tekhelet*, the holiest of all three biblical dyes, the discovery of which was originally reported on in The New York Times (*63*). A detailed scientific report on it will be forthcoming.

We will now travel 200 km due south to get to our final science tour destination.

King Solomon's Copper Mines at Timna

GPS coordinates:
N29.7823, E34.9562

Web sites:
Timnah Park:
http://www.parktimna.co.il/EN/

The Central Timna Valley Project (CTV):
http://archaeology.tau.ac.il/ben-yosef/CTV

The Timna Valley National Park, located in the southwestern Arava, about 30 km north of the city of Eilat, is an expansive 15,000-acre area encompassing beautiful geologic scenery, such as unusual rock formations, and important antiquities spanning millennia of copper-mining history. At the Visitors Center, a multimedia presentation portrays Timna's fascinating story from Egyptian times to the present. Fun activities are also available at the park and these include climbing through rock pillars, pedal boating on the lake and crafting colored sand bottles with the minerals in the area.

The archaeological and scientific background to this historic site has recently been published in a comprehensive article by Dr. Ezer Ben-Yosef *et al.*, which contains a good archaeological and scientific background to this historic site (*64*). The archaeology connected with Timna's copper production goes back three millennia. In the Arabah region, the smelting sites at Timna were considered to be the southern complement to the copper site in the northern Arabah site of Faynan (today's Jordan). Early on, based on ceramic finds and historical considerations, scholars have dated these two sites as both forming cooperative enterprises from the Iron Age II time frame, about the 10th cent. BCE (*65*, *66*). This date would thus be contemporaneous with King Solomon's rule over Ancient Israel, which included this territory (*11*). Figure 11 shows the famous iconic sandstone pillars, known as Solomon's Pillars, from the Timna Valley, and chunks of copper ore unearthed at Timna are shown in Figure 12.

However, the discovery of an Egyptian temple in the 1960s and a reappraisal of the ceramic typology by other archaeologists swung the copper production site back to older dates, 14th–12th cents. BCE (*64*, *68*). The pottery found at the smelting sites, as it was claimed, was similar to the style found at the Egyptian sanctuary at the time of the Pharaohs Seti I and Rameses V (19th and 20th dynasties) of the Egyptian New Kingdom, spanning the Late – Early Bronze Age. Thus, the legend that at this site the main copper production occurred during King Solomon's time lay in ruins.

The scientific story now swings back to only a few years ago, when Ben-Yosef reports on new dating measurements that were done at this site (*64*). The newer archaeo-metallurgical analyses were based on radiocarbon dating of short-lived organic samples via the high-precision AMS methodology coupled with high-resolution archaeo-magnetic dating of the artifacts themselves. This was the first time that absolute dates for the main copper production were evaluated for this Timna Valley site. Previously, relative dating was established at Timna based on ceramic typology and a comparative scrutiny of the material culture. The determination of accurate dates for the different phases of copper production in this Arabah region is important for the understanding of the social, economic, and political environment at the time as well as reconstructing the material culture.

Figure 11. Sandstone columns known as the "Pillars of Solomon" in the Timna Valley. (image from Wikimedia Commons).

Figure 12. Copper ore pieces found at Timna. (image courtesy of Erez Ben-Yosef).

Ben-Yosef reported on radiocarbon dating measurements on a number of organic samples, such as wood twig and bark, olive pit, grape and date seeds, as well as charcoal, found at this site. Finding charcoal at a metallurgical processing site is important as this raw form of carbon was the reducing agent in antiquity that was needed for the reduction of copper ore to elemental copper by the uptake of oxygen from the ore. It is important to note that radiocarbon dating of this woody sample would pre-date the activity of the actual site by about a century since it takes time for the plants and trees to grow before they are cut down for burning into charcoal.

The radiocarbon measurements produced new dates for Timna and showed that there was indeed significant Iron Age I – II copper production, which was after the Egyptian presence in the region. Thus, the most recent evidence shows that the main copper smelting sites in Timna do belong to the 11th – 9th centuries as originally proposed, which would be the approximate time line of King Solomon's reign in Ancient Israel. Further, it would also place the Timna and Faynan sites to be contemporaneous with each other.

Hence, the legend that this Timna Valley site is part of King Solomon's empire is on firm grounds and intact. At the conclusion of this science tour, we can head down south and enjoy the rest and relaxation that the warm resort city of Eilat provides and swim in the Red Sea, full of interesting marine zoology. But this can wait for the next science tour.

Conclusions

Our journey to some of the more famous archaeological sites from Ancient Israel has provided us with the opportunity to understand the scientific analyses that were performed on various cultural heritage objects found at these locations. These historical artifacts were studied by an international cast of scientists teaming together to understand our shared past. Many of the archaeological objects have yet to be analyzed and wait for the next generation of scientists who will participate in the next scientific study tour of Ancient Israel.

Acknowledgments

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Chapter 16

Flights of Fancy

World Heritage and Other Sites in Egypt, China, Peru, and Mexico

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Study tours in the history of chemistry need not be confined to those sites, largely in Europe, where the institutions of Western science—chemistry included—were developed. After all, human beings have been doing chemistry throughout the world for millennia before the science of chemistry was born. This chapter imagines study tours in the history of chemistry based on chemical technologies and their artifacts. Possible itineraries are outlined for four countries on four continents: Egypt, China, Peru, and Mexico.

Introduction

When I was invited to participate in the symposium that gave rise to this volume, my assignment was to imagine a study tour in history of chemistry outside Europe and North America. Which sites in Asia, Africa, or South America might such a tour visit? I had to keep it at least somewhat realistic, not stretching either travel time or funds beyond reasonable limits: I couldn't have my travelers in Marrakesh one day, Timbuktu the next, and Kathmandu the day after. This was going to be great fun for an armchair traveler—no jet lag or lost luggage!

When after a lapse of several years, I was invited to contribute to this volume, I was a bit reluctant to set down my imaginary itineraries alongside those that describe actual travels. Furthermore, the four countries on which I decided

In Science History: A Traveler's Guide; Orna;

to focus—Egypt, China, Peru, and Mexico—are hardly novel destinations to tour operators. I choose to dispel these misgivings by means of a prominent disclaimer: the itineraries are based on armchair research rather than actual travel. They are expressly intended as food for thought about travel to sites rich in historical chemistry but outside the nations traditionally associated with the establishment of chemistry as a scientific discipline.

The theme I decided to explore was the history and pre-history of chemical technologies. After all, material culture comes in large part from chemical technologies. Many ancient peoples developed a variety of chemical technologies before they developed writing. Some of these technologies left long-lasting traces: mining and metallurgy, pottery, glass, and inorganic pigments. Some of them left less durable artifacts, such as textiles, organic dyes, paper, and various food-making processes (including baking and fermentation). The former ought to be accessible at archeological sites and the latter at living history museums or displays of traditional crafts. So I turned my attention to destinations rich in archeological antiquities.

The first two resources I examined were Joseph Lambert's book *Traces of the Past* (*1*) and the UNESCO list of World Heritage sites (*2*). Lambert's book is about the application of chemistry to archeology, not the other way around. That is, it examines how modern analytical chemistry can shed light on archeological objects, not on how archeology can uncover the history of chemical technologies. It mentions many archeological treasure sites of the world, and thus it proved to be a useful starting point for ideas of where a traveler in search of ancient chemical technologies might look. Many of the same sites cited by Lambert are listed by UNESCO—along with many more recent cultural sites as well.

Eventually, I narrowed my geographic focus to Egypt in Africa, China in Asia, and Peru and Mexico in Latin America. All of these nations have fairly well developed tourism industries that include their antiquities. I also broadened my focus within these nations from strictly archeological sites relevant to chemistry and chemical technology to include museums as well as sites of more recent and even ongoing chemistry and chemical technology. I have either verified or updated information about sites to make sure they were still in operation in 2014. For each site, I have provided a reference that includes a reliable internet source, where possible, and coordinates from Google Earth. (All web links were working as of spring 2014.)

So sit back, relax, and leave the flying to us…

Egypt

The tombs of the Pharaohs were treasure troves of artifacts. When they were uncovered, they contained examples of glass, ceramics (pottery), and metals. In addition to these durable inorganics, some human and animal remains were preserved by chemical processes known collectively as mummification. Before I began looking into Egyptian antiquities, I had been unaware that some sites contained paintings—ancient pigments.

A chemical history and technology tour to Egypt would have Cairo as the point of entry and exit and home base. (See Figure 1.) One can fly non-stop from New York to Cairo and back non-stop on Egyptair for just over $900. Several European carriers offer one-stop fares for less than $800—in some cases for close to $700 (*3*).

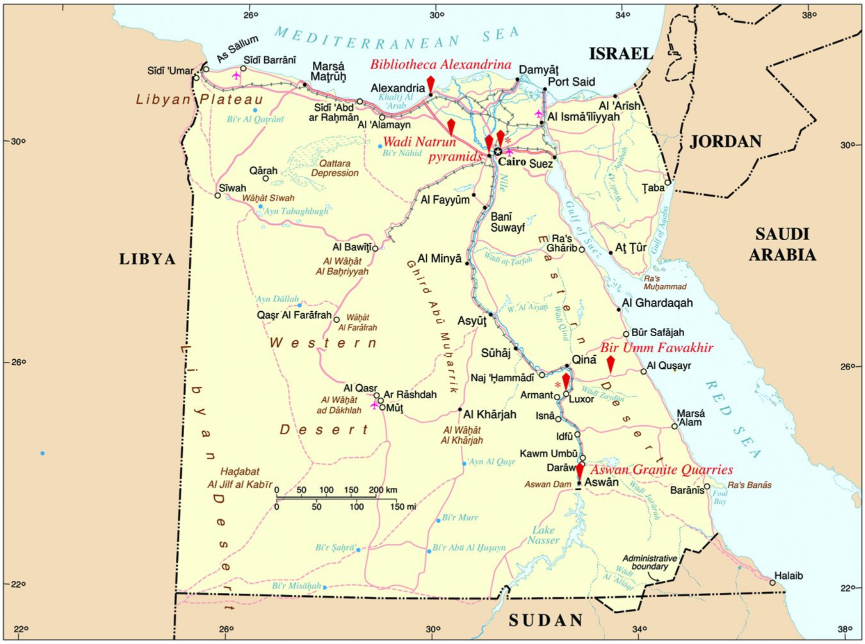

Figure 1. Map of Egypt showing tour stops. (Asterisk indicates multiple stops in the vicinity.)

Cairo and its environs have several attractions for the chemical tourist. The Egyptian Museum (*4*) is the main museum for Egyptian antiquities. It has mummies, both human (in the Royal Mummy room) and animal. Most of the artifacts from King Tutankhamun's tomb are there—other than the king's body and whatever treasures happen to be on tour or on loan. These artifacts include gold, glass, pottery, and textiles.

The Museum of Islamic Art (*5*) in Cairo contains metal work, pigments, textiles, and ceramics from the Islamic era, mainly from Egypt and the Arab world. Brass astrolabes, Damascene swords, Turkish carpets, and examples of glass and ceramics are among the objects on display.

Another interesting site in Cairo is the Pharaonic Village (*6*), which is apparently a cross between a living history museum and an ancient-Egypt theme park. Indeed, the village's website embraces both identities, describing itself as a "Williamsburg-type village" suitable as a setting for documentaries or other films, and at the same time advertising its "Tut Land" amusement park for the kids. Set on an island in the Nile, the village includes exhibits on papyrus, mummification, and ancient Egyptian technologies as well as dioramas and reproductions of some of the glories of ancient Egypt. It also contains a museum of Islamic history, including scientists and philosophers, arts and crafts. The operation was founded by Dr. Hassan Ragab, an engineer who re-introduced papyrus plants and papyrus-paper production to the banks of the Nile near Cairo. The Pharaonic Village is now run by Ragab's family.

No visit to Cairo would be complete without seeing the pyramids of Giza (*7*). Cairo and its suburbs have spread right up to these ancient wonders. (See Figure 2.) Their site is practically an urban historic park.

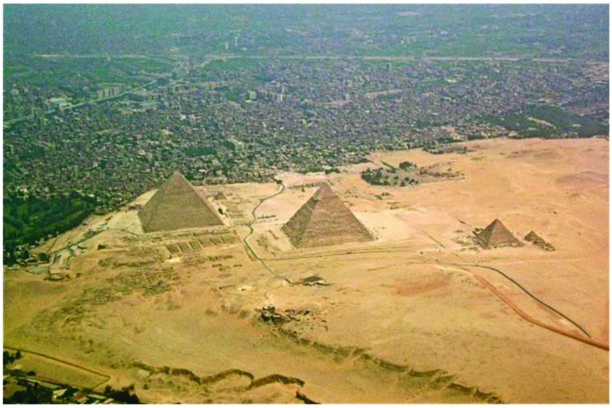

Figure 2. The pyramids at Giza, where the city meets the desert. (From Wikimedia Commons, http://commons.wikimedia.org/wiki/File:Giza-pyramids.JPG).

A side trip to Alexandria, northwest of Cairo on the Mediterranean coast, would also be worthwhile. One can make the trip by train in two or three hours. The Bibliotheca Alexandrina (*8*) opened in 2002 near the site of the ancient library of Alexandria, which was destroyed in antiquity. The new library is intended to commemorate the old and to become a center of culture and scholarship in the Mediterranean world. Its architecture is striking: its looks something like a discus stuck into the ground at a slight angle, allowing light into the main reading room. (See Figure 3.) An exterior granite wall has glyphs of all sorts carved into it. Inside there is a museum of rare books and manuscripts—artifacts dependent on the chemical technologies of paper and ink. The complex also includes a planetarium that contains a museum of history of science, presented chronologically in eras of Egypt of the Pharaohs, Hellenistic Alexandria, and the Arab-Islamic Middle Ages.

The tour would also go upstream along the Nile from Cairo to the temples of ancient Thebes. The modern city of Luxor is on the east bank of the Nile, the same side as the ancient temples of Luxor and Karnak. A small but extensive Mummification Museum can also be found in Luxor (*9*). On the opposite bank (accessible by ferry) are the tombs of the Valley of Kings and Valley of Queens and the ruins of the ancient capital, Thebes. The monumental architecture at these sites is decorated with reliefs. There are also painted surfaces in some of the tombs and temples and even on the undersides of some outdoor surfaces. On the west bank, the Temple of Queen Hatshepsut (*10*), a rare female ruler of ancient Egypt, contains examples of ancient paintings. See Figure 4.

Figure 3. Bibliotheca Alexandrina. (From Wikimedia Commons, http://commons.wikimedia.org/wiki/File:GD-EG-BibAlex-Ext_depuis_parvis.JPG).

The valley is a region of ongoing archeological research. A necropolis containing about 50 mummies was announced by Egypt's Antiquities Minister in late April 2014 (*11*).

It would be interesting to visit a site associated with mining or minerals. Several ancient mining sites are known, many of them in the deserts east or west of the Nile. For example, remains of a gold mine and mining community active in the 5^{th}-6^{th} century CE have been surveyed and explored at Bir Umm Fawakhir in the eastern desert (*12*). Many ancient Egyptian stone quarries were studied and described by the QuarryScapes project (*13*). A map of stone quarries of ancient Egypt and a description of the current state of many of them can be found in Per Storemyr's contribution to the QuarryScapes project. Storemyr's map shows many sites along the course of the Nile, many of which are largely intact but few of which are completely so. Not surprisingly, most of those in the Eastern Desert and Red Sea Hills are intact (*14*).

Which site to visit depends largely on the group's interest in and comfort with the desert. The Bir Umm Fawakhir site is accessible by road. It is about halfway between the Nile and the Red Sea. From Luxor, drive north along the Nile; turn right at Quft onto the road to Quseir and go about 80 km into what appears to be the middle of nowhere. Visiting it would be more like field work than a visit to a museum. On the other hand, the Aswan Granite Quarries, including the quarry of the unfinished obelisk (*15*), are in a UNESCO World Heritage site, in a city relatively easy to get to by train or by air, and near many other sights of interest to visitors (including the Aswan High Dam and Lake Nasser).

Before leaving the topic of minerals, I must point out an area whose name is reflected in the first column of the periodic table. The Wadi Natrun is a valley containing several lakes, many of which shrink considerably in the summer, leaving behind evaporites rich in natron. The deposits are a mixture of sodium salts, primarily carbonate. The chemical symbol for sodium derives from this word, *natrun* in Arabic, *natron* in Greek, *natrium* in Latin (*16*). The Wadi is about halfway between Cairo and Alexandria, just west of the Nile Delta. A small town called Wadi Natrun City is accessible by bus from Cairo. The lakes are apparently favorites of bird-watchers. The area is also historically significant to Coptic Christianity, and is home to several monasteries that have been in use since before the advent of Islam (*17*).

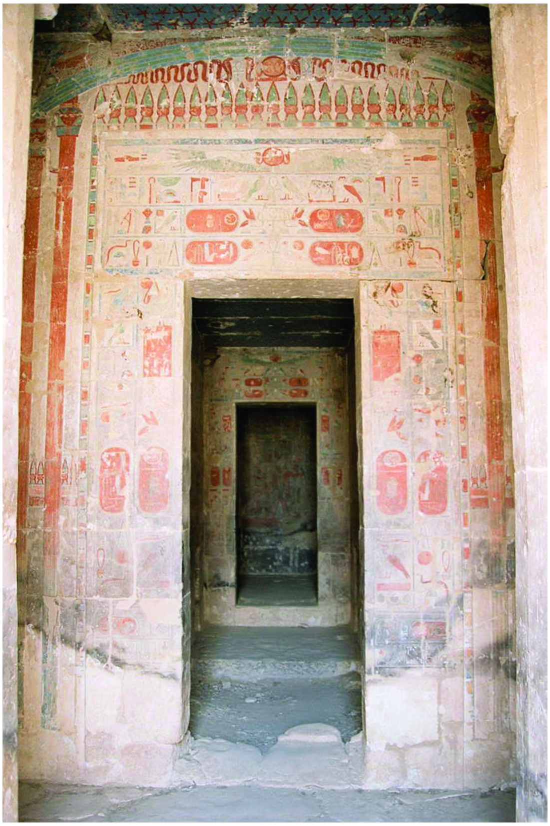

Figure 4. Painted walls in the Temple of Hatshepsut. (From Wikimedia Commons, http://commons.wikimedia.org/wiki/File:Luxor,_sanctuary_inside_Temple_of_Hatshepsut,_Egypt,_Oct_2004.jpg).

One of the challenges of a tour like this stems from the fact that neither guidebooks nor the sites themselves concentrate on chemistry or chemical technology. The *Atlas of Ancient Egypt* by John Baines and Jaromír Malék is an excellent guide to Egyptian antiquities, more like an illustrated scholarly book than a guidebook, but still not specifically for chemical or scientific tourists (*18*).

Human guides knowledgeable about chemical aspects of various collections would provide extra value to such a tour, pointing out objects that general-purpose visitors might just pass by. Making contacts to identify such guides is a challenge. Museums or other institutions to be visited may be a good place to start; they may have appropriate curators or researchers.

Individual contacts are not to be discounted, though, particularly in light of personal networks and computer networks. If I were making this trip, I would consult more extensively with Robert Johnston, the director of the Noreen Reale Falcone library at my home institution, Le Moyne College. Bob lived in Cairo for seven years, working as a librarian at the American University in Cairo. He would put me in touch with Egyptologist and animal mummy researcher, Salima Ikram among others. The point of this anecdote is not to recommend Johnston for contacts or Ikram for guidance. Rather, it is to suggest that even small institutions remote from the site of a tour have the possibility of connecting a tour planner to local experts in a relatively small number of steps (*19*).

China

Like Egypt, China has an ancient civilization, many of whose relics have survived to the present. Many chemical technologies either originated in China or were discovered there independently of discoveries elsewhere. Europeans identified four great inventions of ancient China, a list later embraced in China and showcased in the opening ceremonies of the 2008 Beijing Olympics (*20*). The canonical four inventions are the compass, gunpowder, paper, and printing; clearly chemistry is represented there. A 2008 exhibit at the China Science and Technology Museum in Beijing proposed a different set of four in which chemistry is also prominent: bronze, silk, porcelain (also known as "china" after all), and printing on paper (*21*).

The hypothetical tour to China would begin with a flight to Shanghai, a relatively new city by Chinese standards and the most populous in China, and it would remain entirely in the eastern portion of the country. (See Figure 5.) One can fly from New York to Shanghai and back non-stop for about $1500 on United. Non-stop flights from Los Angeles can be had from several American and Chinese carriers in the $1400-$1500 range on several, and one-stop flights from as low as $1250.

The Shanghai Museum (*22*) is a showcase of Chinese history and culture, and it is architecturally striking in its own right. Its galleries of ancient Chinese porcelain and bronze would be particularly relevant to this tour, as would galleries of painting and calligraphy.

Hangzhou, capital of Zhejiang Province and one of China's ancient capitals, is a two-hour train ride from Shanghai (or one hour on the bullet train). It is home of the China National Silk Museum (*23*). The manufacture of silk may not involve chemistry as directly and obviously as the manufacture of porcelain or bronze, but chemistry comes into the process at many stages from raising mulberries and silkworms to printing and dyeing—not to mention the chemistry carried out by the silkworms in making the fibers, chemistry that humans have attempted to mimic. The museum is just south of West Lake, a small, scenic lake which boasts many gardens and pagodas.

The Zhejiang Provincial Museum (*24*) is located on an island in the north end of the lake, connected by causeway to the north shore. Besides providing a vantage point for viewing the lake, the museum contains a good collection of ancient porcelain, including some from the Yue Kiln.

The Yue kiln sites at Shanglin Lake, about 110 km east of Hangzhou (about 150 km by road), are considered to be the birthplace of Chinese porcelain (in the first two centuries CE) Imperial kilns were established there in the Tang and Song periods. Celadon ceramics were produced there for about 1000 years, peaking around the tenth century CE. The sites, which are said to constitute an outdoor museum of celadon, are on the UNESCO World Heritage tentative list (*25*). A visit to these sites would have to be a guided field trip.

Figure 5. Map of eastern China showing tour stops. (Asterisk indicates multiple stops in the vicinity.)

Jingdezhen in Jiangxi Province is the center of today's Chinese china trade and the successor to Yue. One can buy its products in a centrally located porcelain market or at numerous smaller shops around town. The Jingdezhen Pottery Culture Exhibition Area has exhibition galleries and demonstrations of traditional Qing and Ming techniques for making porcelain. There is also a Ceramic History Museum, which shows old pottery and older techniques of manufacture (*26*). A tour of a working factory would also be interesting. Jingdezhen can be reached from Hangzhou by a five-hour bus ride.

After Jingdezhen would come a day devoted to ancient mining and metallurgy. About 150 km west northwest is the oldest mining site in China, at Tongling Village, Xiafan Town, Ruichang City, Jiangxi Province. The 2 km^2 site includes a concentrated area for mining and a more scattered one for smelting. The site was excavated during 1988-93. It was on the UNESCO tentative list of World Heritage sites (*27*). It is the earliest known site in the world where wooden props were used in copper mining. According to carbon dating, the site was active some 3300 years ago—three hundred years before the next oldest known Chinese copper mine.

Another 80 km west northwest, upstream along the Yangzi river, is another ancient copper mining site, this one with a museum. The Tonglushan Ancient Metallurgy Museum and Mine Site has extensive slag heaps. Timbering and smelting areas have been excavated there. The museum is built over some excavated shafts, and it displays some mining tools from the time the mine was active, roughly 2000-3000 years ago (*28*). Another 80 km northwest lies Wuhan, the capital of Hubei Province, where one can find hotels and train or air connections.

A day of travel from Wuhan would take us to Xi'an, capital of Shaanxi Province and one of the ancient capitals of China. (Train travel can be as little as four hours by intercity express or as long as 16 hours by "fast" train.) China's first unifying emperor, Qin Shi Huang, is buried nearby, and his mausoleum is a UNESCO World Heritage site (*29*). Our interest will be in terra cotta and other pottery from the early imperial period and before.

The army of terra cotta warriors near the tomb of emperor Qin Shi Huang, is one of China's most famous attractions. Figures from among the thousands discovered in the 1970s have been displayed at major museums in Europe and North America. One can see them in their natural habitat (protected by a hangar-like building; see Figure 6) and in overwhelming numbers about 35 km east of Xi'an. These are life-size clay warriors, each different. The site and museum are easily reached by bus. Bronze chariots and horses from the nearby emperor's tomb are also on display at the warriors site.

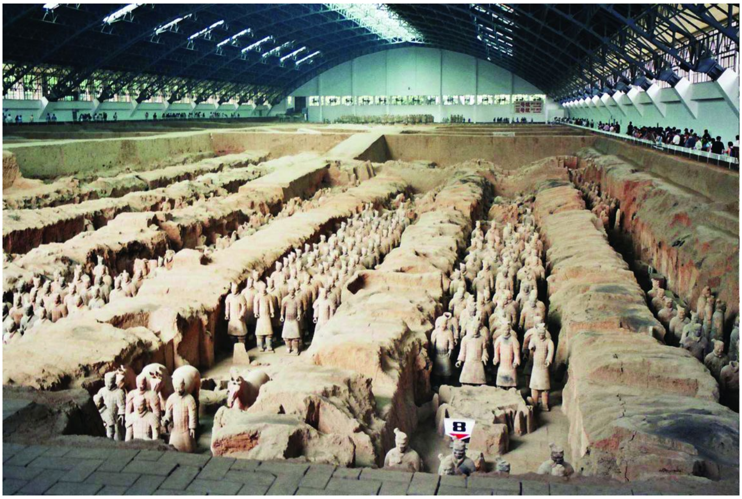

Figure 6. Terracotta army in formation. (From Wikimedia Commons, http://commons.wikimedia.org/wiki/File:Xian_guerreros_terracota_general.JPG).

Banpo is an important Neolithic archeological site nearby, occupied from 4500-3750 BCE. A pottery-manufacturing area including six kilns are among the artifacts excavated. The museum that was first opened at the site has recently undergone a major renovation (closing it in 2004-06). Lonely Planet was not impressed with the old museum (calling parts of it "unbearably cheesy") (*30*). After reopening, even guidebooks that find the museum worthwhile recommend shunning the model village on the site, "unless you're interested in documenting one of China's great tourist oddities" (*31*). The site and museum are on the northeast edge of Xi'an.

I've taken you on a virtual trip to China without visiting its capital. You can visit it as a side trip on your way home. Flights from New York **to** Shanghai and returning **from** Beijing can be arranged for about the same price as round-trip flights between New York and either Chinese megalopolis.

Peru

Much of Latin American history for the last 500 years has been shaped by the interaction between native peoples and more recent arrivals from Europe. Our tour will touch on both indigenous and European cultures and on the stunning natural environment in Peru. (See Figure 7.) One can fly from New York to Lima non-stop for about $850; some carriers have one-stop flights (stopping in Florida) for less than $700. Several airlines fly non-stop from Miami for $700 or less.

Here as on our previous tours, we begin with archeological artifacts in a large museum. The Museo de la Nación (*32*) is a good place to start to get an idea of the confluence of people and cultures that have shaped Peru. It has artifacts from republican, colonial, and pre-hispanic Peru, and its chronological organization helps illustrate the diversity of pre-hispanic cultures that developed within the borders of the modern state. Among its pre-hispanic artifacts are ceramics, metal objects, and textiles.

The Museo Oro del Peru (*33*) is one of the best-known (some would say notorious) private museums of Lima. It received bad publicity in 2001 and 2002 because a substantial portion (estimates range from 10% to a large majority) of its gold artifacts on display were fakes (*34*). It houses two main collections, gold artifacts (as expected from the name) and a collection of arms (mainly swords and guns). Both involve metallurgy, so both are relevant to this tour.

Next we fly to Arequipa, the second largest city of Peru, nestled in the Andes at 2500 meters. From here we take a tour from Geo Tours, Peru, to the Cerro Verde Mine, an open-pit copper mine 24 km south of the city (*35*). Copper, gold, and zinc, are Peru's major export commodities. Gold, of course, was important in Peru before the arrival of Europeans, while mining and metallurgy was an important part of the colonial and post-colonial economy. Copper mining at the Cerro Verde site has been going on since the 19th century and it continues, using what I've seen described as modern hydrometallurgical methods.

While in Arequipa, one may want to visit the Museo Santury (officially the Museo de la Universidad Católica de Santa María), which houses several "ice mummies" and artifacts buried with them (*36*). These are the remains of victims of human sacrifice discovered in recent years in mountains around town. There is nothing particularly chemical here, though, unless you count the refrigerated display case. I remember attending a local ACS meeting in Syracuse in which an engineer from the Carrier Corporation talked about the technical challenges of making a display case cold enough to preserve the remains of the best known ice maiden, Juanita.

Figure 7. Map of Peru showing tour stops. (Asterisk indicates multiple stops in the vicinity.)

It would be a shame to visit Peru without seeing Machu Picchu, which is undoubtedly the nation's best-known cultural attraction, even if the connection to chemistry is tenuous at best. Built in the 15th century, the city was abandoned in the 16th, when Spain conquered the Inca empire. But apparently the Spanish did not know about Machu Picchu, which remained unknown to the outside world until 1911 (*37*). Ceramics and metallurgical artifacts from Machu Picchu are not at the ruins themselves, but many can be seen at the newly established museum at the

Casa Concha in Cusco. This museum is run by the UNSAAC-Yale International Center for the Study of Machu Picchu and Inca Culture, a collaboration between the Universidad Nacional de San Antonio Abad del Cusco (UNSAAC), the Peruvian government, and Yale University. The center opened in 2011, and the focus of its collection are artifacts collected a century earlier and brought back to Yale University (*38*). Cusco is the largest city near Machu Picchu. It may be reached by overnight bus from Arequipa or by air from Lima.

The last major portion of the trip is a jungle adventure into the Amazon rainforest to explore one of the world's richest areas of biodiversity and natural products. First one must fly North to Iquitos, Peru's largest jungle city and the world's largest city inaccessible by road. It is accessible by air and by river, the Amazon (*39*). From Iquitos, one travels by boat down the Amazon and then up a tributary, the Napo river. Our jungle headquarters will be the ExplorNapo Lodge, which has electricity, WiFi, and beds with mosquito netting. It is one of five lodges run by the Explorama company, which also runs the boats. Near the lodge is a 500-meter long canopy walkway, a suspended walkway that hangs about 35 meters off the ground among the trees of the rainforest canopy, offering views of the many species that live up there. The ReNuPeRu ethnobotanical garden, a teaching garden of medicinal plants, is also nearby (*40*).

The extraordinary biodiversity of the Amazon rainforest makes it an area of great interest for medicinal and pharmaceutical chemists of the present. It is also of interest to historians of chemistry because of the role that natural products played in the development of structural and synthetic organic chemistry. That work in the late 19th century and throughout the 20th century may have been done **in** Europe or North America, but much of it was done on materials from Latin America.

I must admit to a kind of perverse pleasure in juxtaposing ecotourism and biodiversity with a dirty old chemical technology like mining. I was even more pleased when I realized that there are sites in Peru that combine the two. I am talking about literally mining a natural product, namely guano. Several islands off the coast of Peru are rich sources of this organic fertilizer rich in nitrates and phosphates. Before we leave, let us journey 140 km north from Lima along the desert coast. In January 2009, a regional government announced plans for a museum of the guano trade to be established on ths island of Don Martï¿½n, about 1 km offshore from the town of Vï¿½gueta (*41*). Don Martï¿½n is the closest guano island to the Peruvian mainland, and several smaller islands lie 5-10 km off the coast between Végueta and Lima. The islands appear on satellite imagery to be nearly all white.

Mexico

Our last itinerary brings us back to North America, to a country that I believe is still off the beaten path for study tours of history of chemistry. I am talking about Mexico, which, like Peru, has been shaped by the interaction between native peoples and more recent arrivals from Europe. One can fly non-stop to Mexico City and back from Los Angeles for $425 and from New York for about $500 I should note that the US State Department has a travel warning in effect concerning crime and violence in Mexico, particularly near the US border (*42*). Our itinerary will fly over that border and keep well south of it. (See Figure 8.)

Our first stop will be the Museo Nacional de Antropología in Mexico City (*43*). It has a large, well organized, and well displayed collection of artifacts from and information about the many pre-hispanic cultures of Mexico including the Aztec, Maya, Olmec, and Toltec. As on other itineraries, I am operating under the belief that a large portion of material culture is based in chemical technologies, evident in ceramics, textiles, metals, and pigments. In addition, perhaps the most recognizable object in the museum is an Aztec calendar stone—an outstanding example of pre-hispanic science—albeit not chemical science. (See Figure 9.)

From Mexico City, we will begin a day visiting sites relevant to the discovery of vanadium by Andrès Manuel del Río. Jim and Jenny Marshall did the legwork for this trek as part of their project Rediscovery of the Elements (*44*). They spelled out the Mexican connection to vanadium in an article in the Winter 2003 issue of the Alpha Chi Sigma publication *The Hexagon*—complete with addresses and coordinates (*45*). Del Río was professor of mineralogy at the School of Mines in Mexico City. In 1801 he analyzed a sample of *plomo pardo* (grey-brown lead ore) from a mine in the Zimapán region of Mexico. After separating the lead, he treated the residue, obtaining results that led him to believe he had found a new element, which he called panchromium or erythronium. We begin at the building where del Río did the analysis, El Real Seminario de Minería in Mexico City, where there is also a statue of del Río. Just over 1 km away is the Palacio de Minería, built during del Río's long tenure. We drive north to the foothills just north of the town of Cardonal to the Purísima del Cardonal Mine site, where the ore may have originated, and we turn west (actually southwest then northwest) to the town of Zimapán a local mining center that has remnants of a smelter that dates back to del Río's time.

We continue west to Guanajuato, where we will spend the next day. Guanajuato, (2000 meters elevation) in the state of the same name was the site of silver mines from the 16th century onward. In the 18th century, the mines in and around the town were the largest producers of silver in the world. The wealth of the mines is reflected in the Baroque and neoclassical architecture of the town. The town and surrounding mines are on the UNESCO World Heritage list (*46*). Highlights include the Valenciana mine and church. The mine once produced 20% of the world's silver. Closed during the Mexican Revolution, it reopened as a cooperative in the late 1960s and is still in operation, extracting silver, gold, nickel, and lead. One can tour the compound (but not enter the active mine) and view an old mine entrance. The Iglesia de San Cayetano was built nearby in the second half of the 18th century by the mine owner. Some say it was to fulfill a vow to the saint that he would build a church if the mine prospered and some say it was in atonement for exploiting the miners. The 19th-century El Nopal mine is now an educational attraction, open for tours.

Finally, if you are tired of mines and don't mind dead bodies, visit the Mueso de las Momias (*47*). In this part of Mexico, bodies are exhumed from graves of those whose families do not pay for their maintenance. Many of the bodies so exhumed are not just skeletons, but are naturally mummified by a combination of the soil and climate conditions. Some of the bodies are on display at this museum.

Figure 8. Map of Mexico showing tour stops. (Asterisk indicates multiple stops in the vicinity.)

Figure 9. Aztec calendar stone (National Museum of Anthropology and History, Mexico City). (From Wikimedia Commons, http://commons.wikimedia.org/wiki/File:1479_Stein_der_fünften_Sonne,_sog._Aztekenkalender,_Ollin_Tonatiuh_anagoria.JPG).

We continue west to another UNESCO World Heritage area, where agriculture and biorefining are on view (*48*). The fields around the town of Tequila in the state of Jalisco are blue with agave, the plant from which the eponymous drink is made and has been made since the 16th century. Distilleries large and small can be found in and around town. Those of Jose Cuervo and Sauza offer regular tours, but we would also arrange to see smaller traditional operations like El Columpio. In addition to the cultivation of agave and its transformation into tequila, the area boasts pre-hispanic engineering in the form of landscape terracing. Tequila is the name of not only the drink and the town but also of a volcano 10 km south.

We fly from Guadalahara (near Tequila) to Villahermosa, the capital of Tabasco state in southeastern Mexico. There we focus on cacao, the source of chocolate (for which the world owes a great debt to the Olmec people). One can visit cacao plantations in the area, as day one of a two-day chocolate segment.

We interrupt the chocolate segment to spend some time at Mayan archeological sites. Mesoamerican pigments await the chemical tourist at the Bonampak Archeological Park, in the state of Chiapas near the border with Guatemala (*49*). Bonampak means painted walls in Mayan, and the frescoes are remarkable. (See Figure 10.) The site dates to the eighth century of the Common Era, but it was lost and forgotten until 1946 because of its deep jungle location.

Figure 10. Colored mural from the Mayan ruins at Bonampak. (From Wikimedia Commons, http://commons.wikimedia.org/wiki/File:Bonampak_painting2.jpg; Original Photo © 2004 Jacob Rus Photoshop lighting adjustment by Stephen McCluskey).

The nearest town that has infrastructure for visitors is Palenque, 180 km away (still in the state of Chiapas). As long as we are going to Palenque to visit Bonampak, we have to see the extensive and impressive remains of a large Mayan city in the Palenque Archeological Park. Palenque is a World Heritage site (*50*), one of the finest Mayan sites in Mexico.

On our way back to Mexico City, we spend a day in Oaxaca City, capital of Oaxaca state, for part two of our chocolate pilgrimage. Oaxaca is a major center of chocolate culture, including production of chocolate from cacao, chocolate markets, and chocolate cuisine. Among the treats here are traditional Mexican chocolate dishes such as hot liquid chocolate into which one dips bread and various mole dishes that combine chocolate and spice. If there is time before our return flight from Mexico City, we can visit a site of large-scale chocolate production, the Nestlé factory in Paseo Tollocan near Mexico City. Nestlé has recently added a museum/display building that has received much attention for its unusual design and rapid construction (*51*).

Conclusions

The practice of chemistry is ubiquitous in human societies, and it has been from the beginning of civilization. Therefore, the chemical-historical tourist can find material for study wherever human material culture has been well preserved. Tours like the ones outlined above should be feasible in many places throughout the world—not just in Europe or even in the countries on which this chapter focuses. In addition to readily accessible artifacts of past material culture, though, a certain infrastructure is needed: transportation systems to permit access to foreign visitors as well as facilities for food and lodging.

Traditional travel guides, some of which are listed among the references of this chapter, can be helpful for practical details of transportation, food, and lodging. They are not, however, very good sources for niche sightseeing of the sort considered in this volume. Some of the sites described above are not to be found in mainstream travel guides. Others are dismissed as not picturesque or of widespread interest.

Because reputable mainstream travel guides lack some of the specific information needed to visit some of the specialized sites mentioned above, local expertise can be valuable, if not essential. Visits to field sites, archeological sites that lack visitor centers, or mines (ancient or modern) should not be undertaken without more detailed information than has been given here. Indeed, no savvy traveler ought to depend on an itinerary prepared by an armchair traveler.

Finally, international travelers must keep an eye on the geopolitical situation in and near their destination. As mentioned above, Mexico is the subject of a travel warning by the US State Department at both the time of writing (2014) and the time of the symposium on which this volume is based (2009). Egypt, on the other hand, has been the site of political upheaval on and off since 2011. It is currently (2014) the subject of a travel alert, an advisory often tied to specific events and of shorter duration. The US State Department's website on travel warnings and alerts (*52*) is a good source of information for international travelers the world over. Knowing the location of your nation's embassies and consulates is a wise precaution for travelers to troubled destinations.

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2. World Heritage List, UNESCO World Heritage Centre. http://whc.unesco.org/en/list.
3. Airfares are notoriously variable, sometimes even between adjacent seats on the same flight. Therefore, all airfares reported here should be regarded as obsolete by the time the volume is published. They may be used as indicators of the relative expense of travel to the destinations discussed herein. In order to facilitate such comparisons, the same search engine (Matrix ITA software, http://matrix.itasoftware.com) was used on the same date (April 23, 2014) for the same travel dates (May 22-June 3, 2014, with flexibility of one day before or after either date). Likewise, the air travel business is a volatile one, full of mergers and turnover; therefore, carriers mentioned herein may or may not be in business when this article is read.
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