

A TRIBUTE TO THE MEMORY OF

CARL WILHELM SCHEELE

(1742–1786)



BY PROFESSOR GUNNAR SVEDBERG

ROYAL SWEDISH ACADEMY OF ENGINEERING SCIENCES (IVA)

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PRESENTED AT THE 2012 ANNUAL MEETING
OF THE ROYAL SWEDISH ACADEMY OF ENGINEERING SCIENCES

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FOREWORD



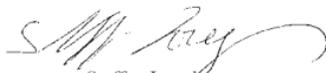
Every year the Royal Swedish Academy of Engineering Sciences (IVA) produces a booklet commemorating a person who was active in Sweden and whose scientific, engineering, economic or industrial achievements were of significant benefit to the society of his or her day. The person to be recognised in the booklet must have died least 100 years ago. The Commemorative Booklet is published in conjunction with the Academy's Annual Meeting.

This year CARL WILHELM SCHEELE, apothecary and chemist, and the first person to produce pure oxygen back in the 1770s, is being commemorated in the booklet. This was an achievement that would change the entire conception of the world at that time and the belief that all matter was made up of the four elements, earth, water, air and fire. In his groundbreaking research, Scheele unlocked the mystery of the nature of air and fire. He summarised his results in a book published in German entitled “Chemische Abhandlung von der Luft und dem Feuer.”

Carl Wilhelm Scheele was elected as a member of the Royal Swedish Academy of Sciences (KVA) when he was just 32 years old, even though he lacked an academic degree. Starting in 1775 Scheele ran an apothecary in Köping and he would remain a loyal citizen of the town until his death in 1786.



Björn O. Nilsson
President of the Academy



Staffan Josephson
Chairman of the Medals Committee

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INTRODUCTION

Carl Wilhelm Scheele's professional career went from being an apothecary's apprentice and journeyman to obtaining his apothecary qualification at a mature age. His background made it difficult for him to be accepted by the traditional academic world with its emphasis on formal academic qualifications. Despite this, while still a journeyman he was elected as a member of the Royal Swedish Academy of Sciences and later as a member of various academies in Germany, Italy and France.

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His life was extraordinary in many other ways as well. He left his family in Stralsund at a young age and spent the rest of his life in Sweden. Even though he spoke and wrote in German his whole life, he is regarded as Swedish in Sweden because he was born in what was then Swedish territory.

Due to Scheele's background as an apothecary, it was natural for his main interests to be chemistry and pharmaceuticals. From the start he studied the materials that were available at apothecaries. This would form the foundation for his future work in organic chemistry and mineralogy. Over the years he developed a significant ability to experiment with organic substances without spoiling the inherent materials. Among the organic acids he produced were oxalic acid and tartaric acid. Today tartaric acid is an important synthetic chemical.

Scheele developed techniques for isolating and purifying many more acids found in fruits and berries. He was also able to identify the acid in sour milk and produce lactic acid. He conducted extensive research into the chemistry of oils and fats. Among other things, he was the first to produce glycerine. This and many of Scheele's other discoveries in organic chemistry have had a great impact on developments in the food and drug industries.

The achievement that is often considered Scheele's most significant one is that he was the first to produce pure oxygen. Unfortunately, his findings were published after those of English scientist Joseph Priestley and French chemist Antoine Lavoisier. Scheele's important work also in-



volved inorganic acids such as nitrous acid, hydrofluoric acid and hydrogen cyanide. His discovery of chlorine has been highly significant in industrial contexts.

Scheele's work in chemical mineral analysis led to a number of discoveries, including several metal acids and metals such as molybdenum, manganese and tungsten.

Scheele's ingenuity, intuition and experimental expertise enabled him to succeed where many before him had failed. Throughout his life as an active chemist, he worked in an apothecary rather than in a university laboratory where he would have had fellow scientists with whom to discuss his findings. Much of the equipment he used for his experiments was inferior to the equipment found in better equipped chemical laboratories.

Working with Professor Torbern Bergman at Uppsala University, Scheele, the ingenious experimentalist with an incredible memory and enormous creativity found a university educated colleague who was very familiar with the theories of the day and who was able to open doors for Scheele to be recognised and accepted in broader academic circles. The collaboration between Scheele and Bergman has often been extolled as one of the most creative in the history of science.

FAMILY AND CHILDHOOD



Carl Wilhelm Scheele was born on 19 December 1742 in the town of Stralsund in what was then Swedish Pomerania. He died on 21 May 1786 in Köping. Stralsund, which lies by the Baltic Sea, is now a German town, but between the Peace of Westphalia in 1648 and 1815, parts of the Duchy of Pomerania and the Principality of Rügen belonged to Sweden.

Scheele was the seventh in a family of eleven children. His father was a merchant, but when Scheele was two years old his father's business went into bankruptcy. Despite this setback, Scheele was able to attend school from the age of six. He was not particularly interested in normal school work, but the family's circle of friends included a doctor and an apothecary and they helped spark Scheele's interest in chemistry and pharmaceuticals.

Scheele's oldest brother started to work as an apothecary's apprentice at the Unicorn Apothecary* in Gothenburg with Bauch, the original German apothecary there

*Apothecaries were traditionally named after animals in Sweden and other parts of northern Europe.

who was a friend of the Scheele family. The brother died of typhus in 1754 at just 20 years of age and Carl Wilhelm was able to take his brother's apprenticeship three years later at the age of 14.



Scheele-Haus in Stralsund, the chemist's birthplace

APOTHECARY'S APPRENTICE IN GOTHENBURG

As an apothecary's apprentice Scheele was a very keen learner and was soon able to work on various pharmaceutical preparations alongside the respected and scientifically curious apothecary Bauch. There was a great deal of chemical and pharmaceutical literature available and Scheele spent much of his free time, both day and night, studying chemistry. It went so far that the apothecary wrote a letter to his parents to inform them of his concern that their son could "through his persistent diligence, harm himself because he spends half the nights studying books that are too advanced for him."

During those early years in Gothenburg Scheele repeated numerous experiments that were described in the chemical literature of the day. In doing so he often questioned previously published conclusions and prevailing notions and developed a critical attitude towards authorities. On one occasion he said that he never believed in chemical facts until he had tested them in his own experiments. Through his experiments and without a systematic scientific education, he built up a broad base of knowledge on his own. His memory capacity was enormous and he seldom had a preconceived notion about how nature should behave. This allowed him to question the opinions of the day.

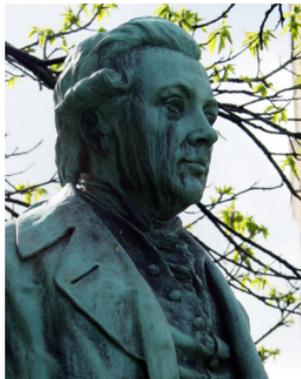
Scheele passed his journeyman test after six years in Gothenburg but stayed on another two years until the apothecary was sold in 1765. He then went to work with an

apothecary called Kjellström at the Spread Eagle Apothecary in Malmö. Kjellström had also been an apprentice of Bauch. He shared Scheele's interest in chemical experiments and allowed him to use the apothecary's laboratory to conduct experiments. Scheele used his earnings to purchase modern literature on chemistry and pharmaceuticals in the nearby cultural and trading city of Copenhagen.



Spread Eagle Apothecary in Malmö, 1870

FIRST CONTACTS WITH ACADEMIA



Anders Jahan Retzius

In Malmö he came into contact with his contemporary Anders Jahan Retzius (1742 – 1821). Unlike Scheele, Retzius had studied at university until he was forced to interrupt his science education for financial reasons. He trained as an apothecary instead because it was a shorter education, but after his apothecary exam in 1761, Retzius returned to his university studies. In 1764 he became a senior lecturer in chemistry at Lund University. The two men worked together on experiments and Scheele learned, among other things, the importance of documenting his work thoroughly.

Retzius was very impressed by Scheele's extensive knowledge and "extraordinary genius in experimentation," particularly in light of the fact that he lacked any formal education. Retzius himself continued his academic career and in 1768, he was also offered a position as a senior lecturer in natural history. He later became a professor in the subject. In 1771 he started the Physiographic Society in Lund, which is still an active royal Swedish academy.

The oldest documents written by Scheele consist of his correspondence with chemists in Lund, especially with Retzius. At that time exchanging letters was the standard form of communication. Scheele's manuscripts are difficult to decipher, even for experienced science historians. They are written in an ungrammatical old form of German and in a script that is extremely hard to read. There is still believed to be plenty for chemistry historians to learn in the documents he left behind in which he describes some 20,000 experiments.

For Scheele, corresponding by letter would be particularly important because throughout his life as an active chemist he would work at an apothecary and not at, for example, a university laboratory where there would normally be several other scientists to discuss things with. Much of the experimental equipment he used was not of the same quality as would be found in better equipped chemical laboratories.

Scheele wrote his first science paper during his time in Malmö. However, with only a background as an apothecary journeyman, he was not able to formulate his writings so that they could be accepted in the academic world. In a paper he sent to the Proceedings of the Academy of Sciences (*Vetenskapsakademiens Handlingar*) in 1768, he described his work on isolating what would later be called oxalic acid. One of the prominent chemists of the day, Professor Torbern Bergman at Uppsala University who was a member of the Academy, reviewed his paper and found that, in his opinion, it hardly contained anything new. A few years later Scheele and Bergman would enter into a very fruitful collaboration.

Scheele also tried to publish his work on producing tartaric acid from potassium hydrogen tartrate, but was unsuccessful in publishing this work as well. He informed Retzius about his problem. Retzius repeated the experiments and published an article in his own name entitled “Experiment with potassium hydrogen tartrate and its acid” in the Proceedings of the Academy of Sciences in 1770. He clearly stated that the work was conducted with Scheele, who he characterised as “a fast *Pharmaciae Studiosus* who was hungry for knowledge.”



Raven Apothecary in Stockholm

good relationships with chemists in Stockholm. The lack of a formal academic degree was probably the reason for the sceptical attitude of the Academy of Sciences towards his results. After just a couple of years, he moved on to work with an apothecary in Uppsala named Lökk at the Apothecary of the Arms of Uppsala (later renamed the Lion Apothecary).

Scheele stayed in Malmö for three years before moving in 1768 to the Raven Apothecary in Stockholm. Although he did not have the chance to conduct his own experiments as he would have liked, he had by this time gained greater notoriety as a skilful chemist. He mingled with a number of prominent doctors but never developed particularly

COLLABORATION WITH TORBERN BERGMAN IN UPPSALA



Torbern Bergman

In Uppsala Scheele got to know chemist Johan Gottlieb Gahn (1745 – 1818), who in his youth had been an apprentice of Carl von Linné (1707 – 1778). Gahn had studied theology before starting to study chemistry. He was a student of the leading figure in Swedish chemical research, the aforementioned chemistry professor Torbern Bergman (1735 – 1784). Gahn introduced Scheele to Bergman and this was the beginning of a very fruitful partnership between the knowledgeable and curious experimentalist and the theoretician schooled in

academia. The same year as Scheele arrived in Uppsala, Gahn moved to Falun where he became active in the mining industry. His collaboration with Scheele and Bergman would continue however, and Gahn would play an important role in several significant advances in the field of chemical science for a number of years to come.

Scheele was initially sceptical about Bergman because he had reason to believe that Bergman, as mentioned above, was behind the rejection of several of his papers by the Proceedings of the Academy of Sciences. The two men learned to appreciate each other, however, and their collaboration continued until Bergman's death in 1784 at

only 49. It was also through Bergman that Scheele, despite only being qualified as an apothecary journeyman, was able to enter the scientific community. The collaboration from 1770 to 1775 between the two men has been characterised by Sten Lindroth (1914 – 1980), a historian of science and ideas, as unique in the history of chemistry.



From a contemporary apothecary

AN APOTHECARY IN KÖPING

His relationship with Bergman in Uppsala also helped Scheele broaden his field to include chemical mineral analysis. But he wanted to eventually have his own apothecary, and in 1775 he took over one in Köping. A 24-year old widow, Margareta Pohl, owned the rights to the apothecary after her husband's death. At the time apothecary privileges were inheritable even though certain skills were required to run one. At Collegium Medicum, which was responsible for supervising the apothecaries in Sweden at the time, Scheele's qualifications were well known and accepted and he was permitted to run the apothecary even though he had no formal qualification as an apothecary. They were prepared to wait for a suitable occasion for him to obtain his formal qualification.

Some eyebrows were raised when Scheele decided to leave Uppsala for Köping. In August 1775 Bergman wrote the following in a letter to Gahn: "Now Scheele has gone. It was hard on both of us to say goodbye; he is running an apothecary in Köping and may have his eye on the widow." In a letter to a good friend, Scheele explained the situation as follows: "You may think, perhaps, that material cares are going to absorb me, and take me away from experimental chemistry. Not at all! That noble science is my ideal. Be patient and you will soon have something new to learn."



Scheele's apothecary and home in Köping

The transfer of the apothecary in Köping went without a hitch. In the summer of 1775 Scheele and the widow Margareta Pohl had agreed that he would run the apothecary for a year with an option to purchase it after nine months. Meanwhile another secret candidate had emerged. But Scheele had apparently become such an important figure as an apothecary in Köping right from the beginning that the people there wanted him to stay. He turned down a number of very attractive offers from Stockholm, Berlin and

London. One of Scheele's comments was the following: "I cannot do more than eat my meat; if I can do that at Köping, I need not seek it elsewhere." He responded to the offer from Berlin as follows: "After mature reflection, I decline it. I lack considerably of being as far advanced in chemistry as such a position requires, and I am persuaded that I shall find my daily bread even at Köping."

At the beginning of 1775 soon after his 32nd birthday, Scheele was elected as a member of the Royal Swedish Academy of Sciences without an academic degree and before he had received his apothecary qualification. He was formally granted that qualification on 11 November 1777 in Stockholm before the Collegium Medicum in connection with his induction into the Academy of Sciences. The Academy decided to award him an annual grant of 100 "riksdaler" (kronor) towards his research. The trip to Stockholm was apparently the only time Scheele left Köping during the remaining period of just over a decade until his death. It is worth noting here that,

Monument of Carl Wilhelm Scheele at Köping Church



according to the apothecary ordinance of 1698, which remained in force well into the 1900s, an apothecary was to be available “day and night, on weekdays and Sundays, always the same.”

Scheele suffered in the final years of his life from what he called gout. On 18 May 1786, when he obviously understood that he was very seriously ill, he married the widow Margareta Pohl. This would allow her to regain the rights to the apothecary that he had taken over just over a decade earlier. Scheele died just three days later on 21 May 1786 at the young age of 43. In Köping’s parish register the reason for his death was listed as consumption. He was buried in the Köping cemetery. The speculation surrounding the contributing causes of his all too premature death included his work with toxic chemicals such as arsenic and prussic acid in his draughty lab in what would today be described as an appalling working environment. Like many other chemists all the way into our own era, he had a habit of smelling and tasting the various substances he produced.



Photo of the epitaph at the church in Köping

SCHEELÉ'S EARLY SCIENTIFIC WORK

Due to Scheele's background as an apothecary, it was natural for his main interests during his years in Gothenburg and Malmö to be chemistry and pharmaceuticals. From the start he studied materials that were available at apothecaries at that time. He had started conducting experiments back in his Malmö days and these would form the foundation for his future work in organic chemistry and mineralogy.

Scheele's ingenuity, intuition and experimental expertise enabled him to succeed where many before him had failed. The first organic acids he produced in pure form while in Malmö were oxalic acid and tartaric acid. The problems he encountered trying to get his findings on these two substances published were described above.

The plant called wood sorrel (*oxalis acetosella*) contains oxalic acid and, through boiling and crystallisation, it was possible to produce sorrel salt (*sal acetosellae*) which although poisonous in large doses, was popular due to its pleasant sour and refreshing taste. Based on this salt, Scheele produced oxalic acid. He produced tartaric acid from potassium hydrogen tartrate, which is the substance that is deposited when wine is stored. Tartaric acid's soluble salts quickly became adopted as a remedy for melancholy and mania. Today tartaric acid is, among other things, an important synthetic chemical.

Scheele developed techniques for isolating and purifying many more acids found in fruits and berries. He was also able to identify the acid in sour milk and produce lactic acid.

Scheele's interest in organic chemistry was always present. Over the years he had developed a significant ability to experiment with organic substances without spoiling the inherent materials. During his time in Uppsala he conducted extensive research into the chemistry of oils and fats. From various types of oils and fats he managed to produce a liquid substance with a sweet flavour and unusual properties which he called "*fat sweetness*". Subsequent studies conducted by French chemist Chevreul (1786 – 1889) have showed that the substance Scheele produced was glycerine.

Many of Scheele's discoveries in organic chemistry have had great significance in the food and drug industries etc.

Glycerine (or glycerol) can be found in soaps



*ADVANCES IN CHEMISTRY IN SWEDEN
IN THE 18TH CENTURY*

In the latter part of the 17th century chemistry became more and more of a real science. People stopped disputing theological hypotheses and philosophical issues, and academic papers were instead based on observations and facts. Sweden at that time was a major player in the mining industry, both from a technical and scientific perspective. 18th century politicians had great confidence in scientific development, particularly if it benefitted industry.

The great importance of the mining industry was a significant factor in the development of mineralogy. The Swedish Board of Mines (*Bergskollegium*) was created in 1637 to enable the government to supervise the industry. Right from the start the Swedish Board of Mines had a chemical laboratory where apothecary-like work was carried out. However, more knowledge was needed, particularly on how to analyse various minerals and this meant it was particularly urgent for progress to be made in analytical chemistry. To this end, the Swedish Board of Mines established “Laboratorium Chymicum” in 1683. The laboratory was established with royal funding and housed between 1695 and 1708 in Gripenhielska Malmgården on the island of Kungsholmen in Stockholm in what is still best known in Stockholm as the Seraphim Hospital building. The hospital was housed there for more than two centuries from 1752 until 1980.

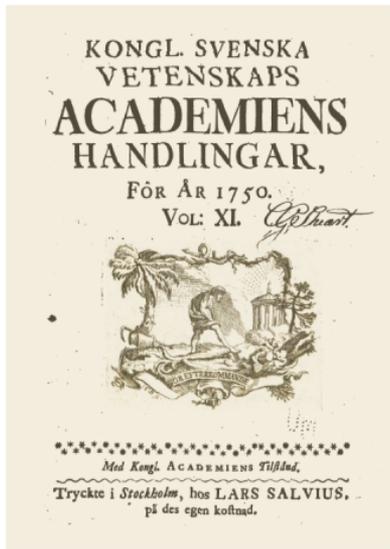


Gripenhielska Matmgården on the island of Kungsholmen in Stockholm

One of the main purposes of the Swedish Board of Mining's laboratory was to meet the mining industry's chemical analysis needs. The first laboratory director was Urban Hjärne (1641 – 1724). He initially studied to become a physician but later made a name for himself as a chemist as well. Hjärne was also the first personal physician to King Carl XI of Sweden. In the early 1700s a number of pioneering discoveries were made at the laboratory in the fields of metallurgy and mineralogical chemistry, one

of which had direct applications in the mining industry. This would be a significant contribution to progress in chemistry.

At that time there was widespread dissatisfaction with what the universities were doing and scepticism about whether the work of university researchers was actually benefitting society and industry. Many people outside academia thought that academics were only working with old and useless knowledge and not producing anything new and useful. Many people wanted a scientific forum whose first priority would be to focus on the requirements and goals of the nation. This was the main reason the Royal Swedish Academy of Sciences (KVA) was founded in 1739. The British Royal Society founded in 1660 and the French Académie des Sciences founded in 1666 served as models. In addition to scientists, the Academy's members would come to include prominent figures in society and industry. The Royal Swedish Academy of Sciences started to publish a quarterly journal called "*Vetenskapsakademiens Handlingar*" (Proceedings of the Academy of Sciences) to gather knowledge and spread it to the public to facilitate its application.

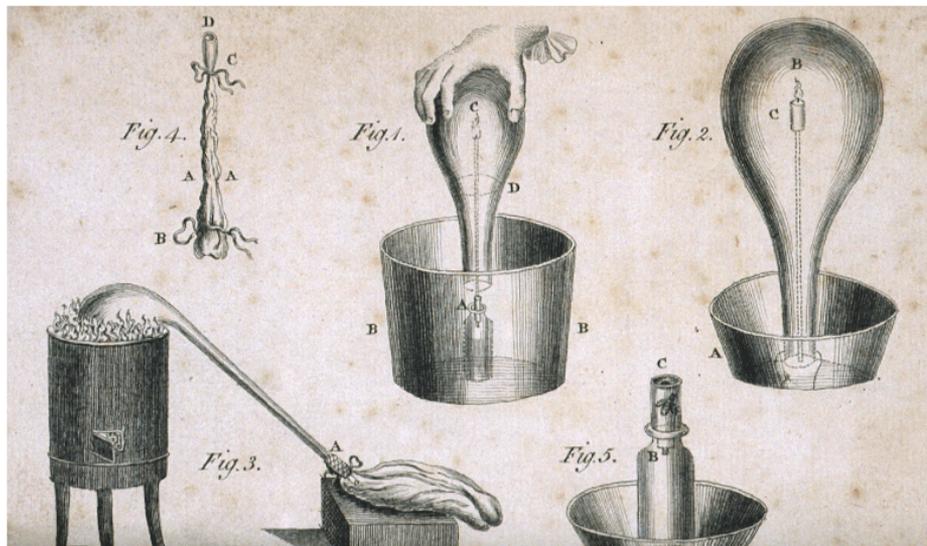


*THE PHLOGISTON THEORY
AND THE DISCOVERY OF OXYGEN*

The achievement that is often considered to be Scheele's most significant is that he was the first to produce pure oxygen. There are numerous scientific articles on the history of this discovery. To understand the discovery of oxygen's great significance to the development of chemistry and later the explanation of oxygen's role in combustion, we need to understand the conception of the world at that time according to which all matter was made up of the four classical elements: earth, water, air and fire. The most elusive elements were the last two. People found it particularly difficult to comprehend what actually happened during combustion.

According to the predominant phlogiston theory, which was launched by German chemist Georg Ernst Stahl (1659 – 1734) at the beginning of the 18th century, all combustible substances contained the hypothetical element phlogiston. Materials that are easily combustible such as charcoal were believed to contain high levels of phlogiston and only yielded a small amount of ash after combustion. It was assumed that the phlogiston disappeared during combustion.

The word "calx" was used for what later became known as metal oxides. Metals were considered compounds of phlogiston and metal calx. This would explain why a



Illustrations of equipment from fire and air paper

calx (metal oxide) when heated with charcoal forms corresponding pure metals to which the phlogiston from the charcoal was believed to be transferred. At the time people found nothing strange in the fact that the calx, after being combined with phlogiston to become metal, became lighter in weight. The concept of mass would not become significant until the French chemist Antoine Lavoisier (1743 – 1794) at the end of the 1780s launched his pioneering theories which refuted the phlogiston theory.

While working as an apprentice in Gothenburg, Scheele studied the standard works of the day in the field of chemistry. He probably questioned parts of the phlogiston theory early on. Still, it would take many years and numerous experiments by several independent researchers in different countries before the combustion process was explained. And although Scheele was the first person to produce pure oxygen, he, like most of the most distinguished chemists of the day, could never completely abandon the phlogiston theory.

The phlogiston theory was also criticized in the 1770s by Lavoisier and the English theologian and scientist Joseph Priestley (1733–1804). Like Scheele, they conducted various chemical experiments to try to solve the mystery of the nature of fire and the composition of air. Even back then scientific development was to a great extent an international issue.

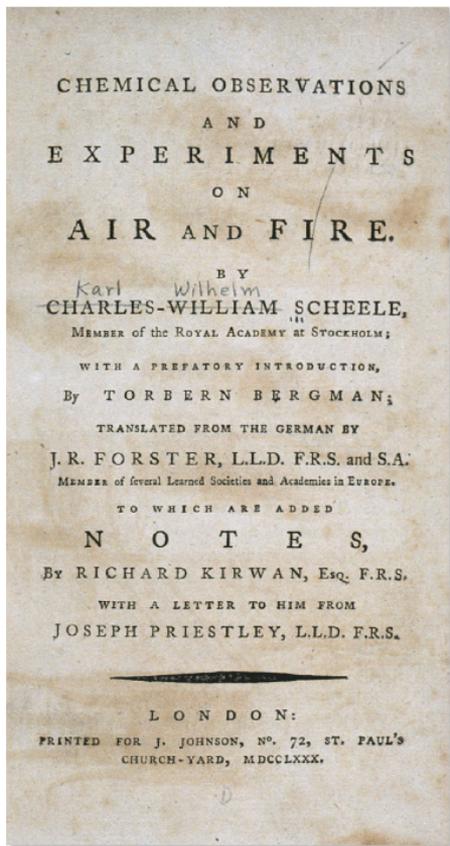
The Swedish mineralogist and geologist, Adolf Erik Nordenskiöld (1832–1901), had become widely known for his polar expeditions and in particular his discovery of the North Eastern Passage. In 1892, in his capacity as a member of the Royal Swedish Academy of Sciences, Nordenskiöld reviewed Scheele's unpublished works ahead of the 150th anniversary celebration of Scheele's birth. He established that Scheele really was the first person to produce pure oxygen in various experiments conducted in 1771 and 1772.

Starting from the end of the 1760s, Scheele conducted a series of experiments with different materials that resulted in the formation of oxygen. In documents dated in the

period 1771 – 1772, he described how when, for example, saltpetre or potassium nitrate and mercury oxide are heated he could identify a gas that he called “fire air” or “vitriol of air”. He was able to collect the gas and he noted that it was colourless, odourless and tasteless, and that it sustained combustion better than air.

In a letter to the secretary of the Royal Swedish Academy of Sciences dated 2 August 1774, Scheele stated that he had been studying air and fire in experiments for a number of years. He pointed out that until that time he had been alone in his knowledge of certain phenomena, but that an Englishman had now come a long way in his research. We can assume that this shows that Scheele was aware that several researchers around the world were trying

Cover picture of Scheele's paper on air and fire



to understand the nature of air and fire as well. He summarised his results in a comprehensive book with the German original title “Chemische Abhandlung von der Luft und dem Feuer,” which was ready to go to print on 22 December 1775. Scheele showed, among other things, that air consists of two different gases, “fire air”, i.e. oxygen, which can sustain combustion, and “vitiated air”, i.e. nitrogen, which cannot. The printing of Scheele’s book was unfortunately delayed for two years, partly because Bergman did not deliver his foreword as promised until 1 July 1777. The work was published the following month, but by then people already knew about oxygen and others had already published some of the material in Scheele’s book. The book was subsequently published in English, French and Latin.

Starting in 1772, Lavoisier conducted a number of experiments with air and combustion. He published his paper “Opuscules physiques et chymiques” in the beginning of January 1774. In it he addressed the effect of air on the oxidation (calcination) of metals, but couldn’t prove which components in air combined with the metal. He sent a copy to the Royal Swedish Academy of Sciences in Stockholm, expressing at the same time his great respect for Scheele. He mentioned that a copy of the paper had been sent to him as well. At that time Scheele and his work were more well-known in other countries than in Sweden.

Science historians have highlighted the great historical significance of a letter that Scheele sent to Lavoisier on 30 September 1774, i.e. at about the same time as Scheele informed the secretary of the Academy of Sciences about his air and fire studies. In the

letter he talked openly to Lavoisier about his experiments in which he produced the new gas that would later be called oxygen.

In 1774 Priestley also conducted experiments that included heating red mercuric oxide and noted that a gas was given off that made candles burn with a more powerful flame. But, like Scheele, Priestley did not realise that it was oxygen. He informed Lavoisier and other scientists of his discovery on a trip to Paris in October 1774. In November 1775 Priestley published his discovery of the new gas he called “dephlogisticated air” in part 2 of his series of articles entitled “Experiments and Observations of Different Kinds of Air.” The very name of the new gas indicates that Priestley was a strong proponent of the phlogiston theory. His theory was that the new gas sustains combustion well because it does not contain any phlogiston and can therefore absorb large amounts of phlogiston during combustion.

In the spring of 1775 Lavoisier presented his work on combustion and a new “kind of air” to the French academy of sciences without mentioning Priestley or Scheele.

After Nordenskiöld reviewed the papers left by Scheele and later studies of them, it was clear that Scheele really was the first person who in autumn 1772 succeeded in producing pure oxygen. But he published later than Priestley and Lavoisier was the first to explain what oxygen is without referring to the phlogiston theory. Later Lavoisier also created a brand new theory on combustion and oxidation, i.e. that the substance being burned combines with oxygen. His theory, which breaks with the phlogiston theory, has often been described as “the chemical revolution.”

ON SOME OF SCHEELÉ'S WORK
IN THE FIELD OF ORGANIC CHEMISTRY

Scheele's early and more important work in the field of chemistry involved both organic and inorganic acids. While in Malmö he produced, among other things, nitrous acid (HNO_2). Scheele's first scientific publication is entitled "Study of Fluorspar and its Acid" and was published in the Proceedings of the Royal Swedish Academy of Sciences in 1771. In it he describes experiments with fluorspar (calcium fluoride) in contact with various acids, bases and salts. When distilled with concentrated sulphuric acid, a volatile acid was formed, which turned out to be hydrofluoric acid (hydrogen fluoride). The acid – which would later be called the "Swedish acid" – is very strong and its discovery attracted a great deal of attention around the world. A contributing factor to this was that Scheele had at first drawn the wrong

Acid-grade Fluorspar



conclusion about what happened when he boiled the acid and obtained a white substance (silicon dioxide) which he called siliceous earth. Scheele thought this meant that the acid when distilled formed siliceous earth. The sceptical foreign scientists claimed that siliceous earth came from the glass apparatus, which Scheele was eventually forced to acknowledge (in a letter dated 1781 to Bergman). He did notice that the acid attacked the glass in the retort, but he had failed to pay due attention to it.

In his 1986 biography of Scheele, Frängsmyr pointed out that there are other points to be made about the history of the Swedish acid. The knowledge that hydrofluoric acid could etch glass began to be used by a French man who in 1788 presented a commemorative tablet of Scheele etched in glass to the Royal Swedish Academy of Sciences. Frängsmyr also points out that history shows that Scheele allowed himself to be convinced when he received scientific arguments as proof.

As mentioned before, Scheele was inspired by Bergman when he arrived in Uppsala to focus more than in the past on various minerals of economic significance for the country. After the discovery of hydrofluoric acid, Scheele continued to study the chemical properties of the mineral pyrolusite (primarily manganese dioxide) in manganese ore, which was previously also called *magnesia nigra*. Many chemists had tackled this over the years but had not made much progress. Scheele studied the mineral's solubility in all known acids. A very important consequence of Scheele's work with pyrolusite was his discovery of chlorine while attempting to dissolve pyrolusite in hydrochloric acid. In a letter to Gahn in 1773 he wrote that hydrochloric acid lost its phlogiston and

became a yellowish gas with a very specific odour. In a subsequent letter he wrote about new observations of the gas he had discovered, including that it reacted as a bleaching agent in contact with textile dyes.

Scheele described his work with manganese ore in his paper entitled: “On manganese ore or magnesia and its properties,” which was published in the Proceedings of the Academy of Sciences in 1774. In it, in addition to the discovery of the new yellowish gas, he reported on the new metal that would later be identified as manganese. Scheele was a supporter of the phlogiston theory and accordingly was inclined to describe the new gas he had found as a compound. He called it dephlogisticated muriatic acid. Later it was Humphry Davy (1778 – 1829) who showed that chlorine is not a chemical compound but an element. Following Scheele’s discovery, chlorine was being used as a bleaching agent in the textile industry as early as the 1780s. Initially Scheele’s method of producing chlorine was used on a large scale before other methods replaced it.

Scheele also made important observations on carbonic acid, phosphorus and phosphoric acid. His work in chemical mineral analysis led to a number of discoveries including several metal acids and metals. One such metal was molybdenum, based on the mineral molybdenite (primarily MoS_2). The mineral had previously been described by Swedish mineralogist Axel Fredrik Cronstedt (1702 – 1765) who called it molybdaenae membranacea nitens. In 1778 Scheele succeeded in dissolving the mineral by treating it in different ways with nitric acid. He obtained a white powder which he called terra molybdaenae (MoO_3). He did not, however, manage to reduce this to a pure metal, but

instead asked his good friend, mineralogist Petter Jakob Hjelm (1746 – 1813) to conduct the reduction in a high temperature oven. Due to improved ovens, Hjelm was able in 1781 to produce the pure metal for which he suggested the name molybdenum.

The mineral molybdenite has many similarities with the better known graphite. In addition to being a raw material for molybdenum production, it is used as an industrial lubricant. The lubricating effect is based on the fact that molybden sulphide molecules are arranged in thin layers. Nanotechnology researchers regard the material as an alternative to graphite and hope that, based on the material's electrical properties combined with the fact that it can be produced in extremely thin layers, it will replace silicon in semiconductors for the electronics industry in the future.

Scheele's experiments also laid the foundation for production of a metal called wolfram (tungsten) based on a mineral called tungsten.



Picture of the mineral molybdenite

(Swedish tung = heavy, sten = stone) because of its high density. Cronstedt was the first to describe this mineral. He had found it in the Bispberg iron mine. When Scheele in 1781 studied the mineral he found that it consisted of limestone and a previously unknown metal acid which was similar to molybdenum acid and which he called tungsten acid. The mineral would later be called scheelite. Two Spanish brothers called d'Elhuyer, who worked as assistants to Bergman, were responsible for producing the pure metal in 1783. The metal was at first called tungsten metal, but would later be called wolfram in Sweden and Germany, tungstène in France, tungsten in Britain and tungsteno in Italy and Spain. The name scheelium has also been used.

Tungsten has the highest melting point (3695 K) of all metals and is therefore used in filaments and light bulbs. Its most important application, however, is as tungsten carbide for the heavy metal industry.



Scheelite

WORK WITH TOXIC CHEMICALS

Unfortunately it was the fate of many prominent chemists to work with toxic chemicals. Back when he was in Malmö, Scheele started working with what would later prove to be the very toxic substance hydrogen cyanide or prussic acid. The source was the pigment called Prussian blue, which was first produced by a German pigment manufacturer at the beginning of the 1700s. Scheele restarted experiments on this substance in Uppsala. He managed to decompose the pigment and described both the odour and the flavour of the colourless liquid he obtained, which was obviously hydrogen cyanide. In letters to Bergman, he called it Prussian blue acid, later shortened to prussic acid. Considering the toxic nature of this substance, it is believed to be a miracle that he survived. The fact that his premature death at the age of 43 may have been caused by hydrogen cyanide was mentioned above.

DEFINITION OF SCHEELÉ'S GREEN

A poisonous yellowish green pigment consisting essentially of a copper arsenite and used especially as an insecticide.

Arsenic is a substance that chemists had known about for many years before Scheele started to show an interest in it. He has described more than 100 experiments where he put arsenic in contact with various compounds and metals. By dissolving arsenic oxide in a warm soda solution and adding copper sulphate, he managed in 1775 to produce a new pigment that would later be named Scheele's Green (CuHAsO_3). The pigment is a strong green colour and, as there was a demand for a stable green pigment at that time, it would come to be widely used.

In his book from 2011 entitled “Evil Chemistry – Tales of people, murder and molecules,” Swedish chemist and professor Ulf Ellervik provides a fascinating description of many examples of what he calls “the dark side of chemistry.” The book includes an account of how the pigment Scheele's Green may have impacted the history of the world. Scheele was himself aware that arsenic compounds were deadly poisonous and clearly pointed this out, but he probably assumed that the risk that a person's body could absorb a sufficient amount of the pigment in order to be harmed



Picture of wallpaper in Scheele's Green

was small. This is not the first time in history that scientists have been unable to imagine how their discoveries could result in serious health risks if not handled correctly.

Despite its toxicity, Scheele's Green would be used for many different purposes. One of the main ones was colouring wallpaper, and green wallpaper was clearly a very popular item in the 1800s. Ellervik described how, back in 1839, the famous German chemist Gmelin wrote a very critical article about the risky use of the pigment, but he did not gain much of a hearing. The wallpaper pigment could be particularly dangerous if it came into contact with damp and mould. Certain types of mould can convert the arsenic in the pigment into a toxic gas called trimethylarsine ($(\text{CH}_3)_3\text{As}$). A highly discussed historical hypothesis is that Napoleon Bonaparte's death in 1821 on Saint Helena was caused by the wallpaper in his damp prison, which in all likelihood contained Scheele's Green.



Wallpaper from Napoleon's Bathroom

CLOSING WORDS

Carl Wilhelm Scheele's life was extraordinary in many ways. He left his family at a young age and would live and work for the rest of his life in a country with a different language to his mother tongue. Even though he spoke and wrote in German his whole life, he is clearly regarded as Swedish in Sweden because he was born on what was then Swedish territory. Like all other nations, Sweden is keen to embrace successful individuals as its own. It is interesting to note, however, that the German version of Wikipedia describes Scheele as German-Swedish.

A desire to understand the chemical make-up of matter was an extremely strong driving force in Scheele's development. He maintained that "the purpose of chemistry is to skillfully decompose bodies into their component parts, discover their properties and combine them in different ways."

His professional career went from being an apothecary's apprentice and journeyman to obtaining his apothecary qualification at a mature age. Because of this background he found it difficult for many years to be accepted by the traditional academic world with its emphasis on formal academic qualifications. However, Scheele gradually convinced his critics of his extraordinarily extensive knowledge in the fields of chemistry, pharmaceuticals and mineralogy.

Scheele gained great notoriety and respect outside Sweden and was elected as a member of various academies, in Germany (Gesellschaft Naturforschender Freunde zu Berlin, 1778 and Churmainzische Gesellschaft der Wissenschaft, 1785) in Italy (Regia Scientiarum Taurinensis Academia, 1784 and Societá Italiana, 1785) and France (Societé Royale de Médecine, 1785). As mentioned above, he was elected before this as a member of the Royal Swedish Academy of Sciences while still an apothecary journeyman.

Working with Bergman at Uppsala University, the ingenious experimentalist with an incredible memory and enormous creativity found a university educated colleague who was very familiar with the theories of the day and was also able to open doors to recognition for Scheele, including in broader academic circles. The collaboration between Scheele and Bergman has often been extolled as one of the most creative in the history of science.

In his biography from 1942 to commemorate the 200th anniversary of Scheele's birth, Fredga makes the following observations:

“To commemorate Torbern Bergman there are no centennial celebrations, nor has any statue been erected. This may in part depend on the fact that Scheele's discoveries stick more easily in people's memories. They stand out as concrete facts, while theoretical and systematic contributions, which once seemed inspiring before losing their import, rarely spark the interest of people outside the circle of authorities on the history of science and ideas. Scheele's fate has also always appealed to people's imagina-

126 1771. Apr. Maj. Jun.

UNDERSÖKNING

Om

Flus - Spat och dess Syra;

AF

CARL WILHELM SCHEELE.

1. Flus-Spat är en märkvärdig Sten-art, i synnerhet för dess vackra phosphorescerande i mörkt rum, efter upvärmning. Men dess beständs delar hafva hittills varit mindre bekante. At om dem vinna underrättelse, har jag antält åtskilliga försök, och härvid nyttjat förnämligast en grön art från Garpenberg, samt en hvit från Gislöf i Skåne.

2. Man vet, at Flus-Spat, som en gång varit fullkomligen glödgad, ej Phosphorescerar efter ny upvärmning. At få veta, om han då förlorar någon af constituerande delarne, har jag låtit 3 unts väl upglödgas i betäckt Digel; han sprakade häftigt, nästan som Koksalt, så snart han blef het. Efter afkylningen fanns knapt något märkeligt af tyngden förloradt, och han förhöll sig i allt lika med obränd, förutan det, at han (a) af ny upvärmning hvarken sprakade eller Phosphorescerade, (b) var mör, eller lättare pulverisabel än förut, (c) var hvit, opak, och den gröna rödaktig.

3. Et stycke Flus-Spat, upvärdt, til dess det blifvit väl lysande, kastades i kalle vatten. Det förlorade strax en stor del; men behöll likväl deruti et dunkelt sten nästan hela timan. I tyror behöll han ock sitt sken; men Solutionen

tions in a different way than Bergman's. Scheele indisputably had a more specialised talent than Bergman, but perhaps that is the very reason why his talent goes deeper and is more original. Scheele was a chemist by nature and calling, Bergman became one through academic promotion cycles.”

Scheele conducted a great many documented chemical experiments, only a small percentage of which were published in some thirty reports in the *Procedures* and the *Academy of Sciences* and in his own book “*Chemische Abhandlung von der Luft und dem Feuer*” from 1777. The first person to later delve deeply into his works was mineralogist and polar explorer Adolf Erik Nordenskiöld. Above is a reference to his review of Scheele's papers before the 150th anniversary of



Scheele's birth. He made the following comments to Scheele's notes: "These notes prove once more that the basic experiments for a large part of Scheele's great discoveries have already been carried out in Gothenburg and Malmö; that the apprentice had already subjected to an exact investigation the entire material offered to a chemist in an apothecary of his time achieving results which, if published immediately, would have made the years 1767 – 1770 a turning point in the development of chemistry."

Following Nordenskiöld's review 1892, chemist and science historian Boklund published large portions of Scheele's laboratory notes in the 1960s as well as his correspondence – the so-called Brown Book, and also commented on these. Scheele's own writings are difficult to read. Numerous more accessible works about his life and work have been published, however, and some of these are listed below.

A quarter of the 92 "natural" elements were discovered by Swedish chemists during the period 1735 – 1879. Scheele's findings were behind a third of these discoveries. This commemorative booklet far from covers all of Scheele's significant achievements.

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