La química en la historia, para la enseñanza.

Guillaume-François Rouelle

*Jaime Wisniak**

Abstract

Guillaume-François Rouelle (1703-1770), a leading French chemist of the second half of the eighteenth century, is considered to have written little but taught much and very well to highly qualified students. His most famous student was Lavoisier, but he also taught chemistry to Darcet, Desmarest, Diderot, Leblanc, Macquer, Proust, Rousseau, Sage, and Turgot among others.

Resumen

Guillaume-François Rouelle (1703-1770), uno de los químicos franceses líderes de la segunda mitad del siglo XIX, se considera que escribió poco, pero que enseñó mucho y muy bien a sus estudiantes, los cuales lograron muy altas calificaciones. Lavoisier fue su alumno más importante, pero Rouelle también enseñó Química a Darcet, Desmarest, Diderot, Leblanc, Macquer, Proust, Rousseau, Sage y Turgot, entre otros.

Guillaume-François Rouelle was born on September 15, 1703 at Mathieu, near Caen, Normandie, the elder of the twelve children of Jacques Rouelle and Marie Bougon, a farming family. His youngest brother, Hilarie-Marie (1718-1779), called Rouelle *le cadet* or Rouelle *le jeune*, in time would become Guillaume's assistant and then replace him in his academic post. Guillaume took his secondary studies at the *Collège du Bois*, at Caen, where his teachers noted his keen interest in sciences. Already as a young man he collected mineral and botanical specimens and cultivated a small garden of rare and curious plants. When he was fourteen years old he rented a coppersmith's forge with its furnaces and utensils, began to conduct experiments, and he even gathered some pupils around him (McKie, 1953; Rappaport, 1960).

After finishing school he enrolled at the University of Caen to study medicine but he abandoned his studies because his sensible personality could not stand performing dissections and treating patients, which were in great suffering. From medicine he turned to chemistry, a subject that had interested him from the very beginning.

In 1725 he left for Paris to further his chemistry studies, accompanied by two fellow students, which shared with him his interest in science. Not wishing to abandon medicine altogether, Rouelle decided to study pharmacy, the branch of medicine that was closer to his favourite science of chemistry and better suited "à la sensibilité de son coeur" (to the sensibility of his heart) than medicine and surgery. In Paris he became apprenticed to Johann Gottlob Spitzley (1690-1750), a German pharmacist who had moved to Paris and taken over the laboratory of Nicolas Lémery (1645-1715)]. Rouelle spent with Spitzley seven years, time where he acquired the habits of order, reflecting observation, and work. He familiarized himself with the different procedures and laboratory work, greatly extending his knowledge, both by experiments and by reading, and also by his contacts with many of the leading French scientists of that time, in particular, the de Jussieu brothers: Antoine (1686-1758) who was professor of botany at the *Jardin du Roi* (after 1793 it became the *Muséum National d'Histoire Naturelle*) and Bernard (1699-1777), the demonstrator in botany (Grandjean de Fouchy, 1770; Cap, 1842).

After 1737 Rouelle began giving lectures in both pharmacy and chemistry in the *Place Maubert*. These lectures soon became popular and attracted people other than aspiring students, with the results that both his doctrines and his personality became controversial subjects. Rouelle's initiative of giving private lectures was not a novelty. From the seventeenth century on it had become very common for scientists to give private courses open to a fee-paying audience composed of interested students and general public. The popularity of these private chemistry courses grew enormously during the career of Lémery whose courses and extraordinary successful book (Lémery, 1675) remained a bestseller during most of the eighteenth century. Lémery brought French chemical teaching out of the Paracelsian tradition into the Cartesian and atomistic natural philosophy; he did not develop any rigorous theories of matter but explained chemical reactions in terms of particle

* Department of Chemical Engineering, Ben-Gurion University of the Negev, Beer-Sheva, Israel 84105.
Correo electrónico: wisniak@bgumail.bgu.ac.il
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shape and movement, the same as Jean-Baptiste Sénac (1693-1779) had done (see Salts, below).

Rouelle's lectures and teaching techniques called the attention of George-Louis Leclerc Buffon's (1707-1788) who, in 1742, appointed him to the post of *démonstrateur du chemie* at the Jardin du Roi. Rouelle taught at the Jardin du Roi until 1768, when he retired due to health reasons. During his tenure his unorthodox teaching methods attracted large numbers of students, formal and informal, which included scientists, writers, and gentlemen of the court, ladies of fashion, students, and others, to all of whom he communicated his enthusiasm. In addition to his formal courses at the Jardin, he continued his private teaching at his laboratory at the Place Maubert; eventually, in 1746, he moved his laboratory and courses to the rue Jacob.

By practice long established at the Jardin du Roi, the lectures were given jointly by the professor and the demonstrator. After an oral exposition by the professor, the demonstrator proceeded to perform the necessary experiments to illustrate the ideas and theories that the professor had expounded. Rouelles professor was Louis-Claude Bourdelin (1696-1777), who customarily ended his lecture with the announcement: "Tels sont, messieurs, les principes et la théorie de cette operation, ainsi que M. le démonstrateur va vous le prouver par ses experiences" (Such, gentlemen, are the principles and theories of this operation, as the demonstrator will now prove to you with his experiments).

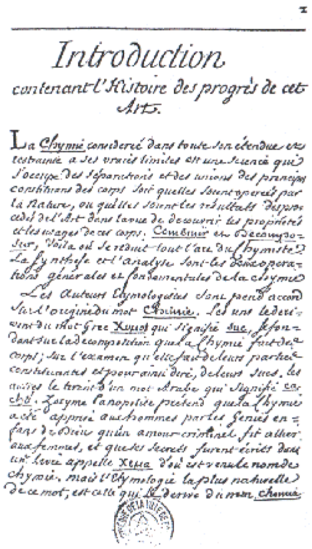
Rouelle's lectures were instrumental both in disseminating his ideas among a wide audience that included many capable students and in securing for him several academic distinctions. His reputation rapidly became such that at the death of Gil-François Boulduc (1675-1742) on January 17, 1742, he was appointed his successor at the Jardin du Roi. Particularly noteworthy is the title of Rouelles position: *Démonstrateur en Chimie au Jardin des Plantes, sous le titre de Professeur en Chimie.* As told by his title, Rouelle conducted experiments and lectured on theoretical matters (Rappaport, 1960).

In December of 1743 Rouelle read a paper on neutral salts (Rouelle, 1744) before the Paris *Académie des Sciences.* This paper was given a favourable report by two academicians, Bourdelin and Jean Hellot (1685-1766), and in the following year Rouelle was elected to the Académie as *adjoint-chimiste* (adjoint in the class of chemistry), replacing Paul-Jacques Malouin (1701-1778), who had been promoted to *associé.* This paper was followed by four more memoirs, which form the major part of Rouelles publications. In 1752 Rouelle was promoted to associé, after the promotion of Bourdelin to the rank of *pensionnaire.* His many absences due to his illness, did not allow him to take the rank of pensionnaire, which became vacant in 1766 when Hellot passed away.

At one time or another almost all the French famous names of the second half of the eighteenth century science, philosophy, and letters studied chemistry with Rouelle, the most important being Pierre-Simon Lavosier (1743-1794). The roster of his students reads like a "who is who" of chemists, physicists, physicians, and men of letters: Théodore Baron (1715-1768), Pierre Bayen (1725-1798), Alexandre-Théodore Brongniart (1739-1813), Jean-Baptiste Bucquet (1746-1780), Jean Darcet (1715-1801), Jacques-François De Machy (1728-1803), Nicolas Leblanc (1742-1806), Pierre-Joseph Macquer (1718-1784), Louis-Sébastien Mercier (1740-1814), Joseph Louis Proust (1754-1826), Rouelle *le cadet*, Augustin Roux (1726-1776), Balthazar-Georges Sage (1740-1824), Pierre-François Tingry (1743-1821), Gabriel-François Venel (1723-1775), and Peter Woulfe (1727-1803). Other famous participants include A.-L. Jussieu, Nicolas Gobet (1735-1781), Antoine-Grimoald Monnet (1734-1817), Nicolas Desmarest (1725-1815), Denis Diderot (1713-1784), Jean-Jacques Rousseau (1712-1778), and Anne-Robert-Jacques Turgot (1727-1781).

Diderot frequently attended Rouelles lectures and took careful notes; his respect for Rouelles chemistry is evident in his "Plan d'une Université Pour le Gouvernement de Russie", presented to Catherine II of Russia, where he recommended the notebooks of Rouelle, "reviewed and corrected and augmented by his brother and by doctor Darcet" as the best possible textbooks to use in teaching a course in chemistry.

Rouelle's lectures opened with some general remarks about the aims and methods of chemistry, followed by an introduction to chemical theory, according to the framework of the course established by Bourdelin. Rouelle defined chemistry as: "La Chymie est un art physique, qui par le moyen de certaines opérations et de certains instrumens nous enseigne a séparer des corps plusieurs substances, qui entrent dans leur composition et a les recombiner de nouveau entre elles ou avec d'autres pour reproduire les premiers corps ou pour en former de nouveaux" (figure 1) (Chemistry is physical art that


Introduction
contenant l'Histoire des progrès de cet Art.

La Chymie considerée dans toute son étendue et restrainte à ses vraies limites est une science qui s'occupe des séparations et des unions des principes constituans des corps soit quelles soient operées par la Nature, ou quelles soient les résultats des procedés de l'Art dans la vue de decouvrir les propriétés et les usages de ces corps. Combiner et Decomposer, voilà où se reduit tout l'art du Chymiste. La synthese et l'analyse sont les deux operations générales et fondamentales de la chymie.

Les Auteurs Etymologistes sont peu d'accord sur l'origine du mot Chimie. Les uns le derivent du mot Grec Χυμος qui signifie suc, se fondant sur la decomposition que la Chymie fait des corps; sur l'examen qu'elle fait de leurs parties constituantes et pour ainsi dire, de leurs sucs. les autres le tirent d'un mot Arabe qui signifie caché. Zozyme Panopolite pretend que la Chymie a été apprise aux hommes par les Genies enfans de Dieu qu'un amour criminel fit attacher aux femmes, et que ses secrets furent écrits dans un livre appellé Χεμα d'où est venu le nom de chymie. mais l'Etymologie la plus naturelle de ce mot, est celle qui le derive du nom Chemia

Figure 1. Page of Rouelle's lectures, giving the definition of chemistry.

through the use of certain operations and instruments teaches us the art of separating bodies into their various component substances and of recombining them again to give either the original substances or new ones), a definition following that of Stahl: "Universal chemistry is the Art of resolving mixt, compound, or aggregate Bodies into their Principles; and of composing such Bodies from those Principles." Here it is important to clarify that the term "instruments" did not refer only to physical equipment; according to Rouelle instruments were *natural* (the four elements) and *artificial* (reactants, solvents, and vessels).

Rouelle believed strongly that theory must be based on experimental evidence and planned his experimental exhibitions to the students accordingly. His method is illustrated by the remark that occurs invariable in his manuscripts: "La chimie ne cherche pas de vains raisonnemens, elle cherche des faits. Lui demande-t-on par exemple ce que c'est que le cinabre, elle répond que c'est un composé de souffre et de mercure, et pour le prouver, elle en retire les deux substances et les fait voir séparées. Elle fait plus, avec du souffre et du mercure, elle compose un véritable cinabre" (Chemistry does not look for vain arguments, it seeks facts. If we ask her, for example, what is cinnabar (HgS), she will answer that it is a compound of sulfur and mercury, and to prove it she isolates the two substances. Not only that, with sulfur and mercury she will compose a true cinnabar).

He accepted the four-element theory of earth and air, fire and water, but replacing fire by phlogiston (the flammable principle); he accepted that these four elements were more capable of accounting completely for the properties of matter and chemical phenomena, than the three ones of Basile Valentin and Paracelsus (1493-1541) (mercury, sulfur, and salt). Rouelle thought that there might be a fifth element, the "mercury" of Johann Joachim Becher (1635-1682).[1] In Bechers view, there were three earths, the vitrifiable, the mercurial, and the combustible (which Rouelle called coloring earth). Although the existence of mercurial earth was not certain he believed that it was present in marine salt and that it was the cause of the metallic nature of metals. All minerals were made of three components in various amounts: terra pinguis (sulfur), terra mercurialis (mercury), and terra lapida (saline component), and all the natural substances contained the terra pinguis, which was lost in combustion. These primordial elements did not combine by themselves to form compounds, but various combinations of them, about ten or twelve in number, which then combined with one another. The transfer of one or more of them from one compound to another in a chemical reaction allowed discovering their properties. The basic tenet was that they were indestructible, immutable, and indecomposable.

Rouelle was still defining the constituent elements of matter as Aristotle had: "We call principles or elements simple, homogeneous, indivisible, immutable and insensible bodies, more or less mobile according to their different configurations, stature and mass, and which are differentiated by their volume and particular shape. It is impossible to detect them in isolation, separated from other elements, unless they come together in a very large numerical quantity. Their particular shape is also unknown and it would be quite ridiculous to pretend to determine it, as several physicists have done. What can be ascertained is that they exist in very small numbers and yet their different combinations suffice to form all the bodies found in Nature. We acknowledge four principles or elements: phlogiston or fire, earth, water and air" (Rouelle, Cours de Chymie, pp. 27-28).

The course content of Rouelle's course was arranged according to the vegetable, animal, and mineral kingdoms, but Rouelle thought that there were three other kingdoms: watery, earthy, and aerial. Contemporary knowledge was well expounded in this systematic way, and there was an extensive account of chemical apparatus and its uses, especially of the process of distillation. Rouelle was familiar with the work of Robert Boyle (1627-1691) and of Stephen Hales (1677-1761) on air, and he considered air entered into the composition of bodies. Rouelle

[1] Rouelle is considered to be the one who introduced the phlogiston theory in France (Rappaport, 1961). His most famous student, Lavosier, is credited with putting this theory to rest.

believed that air could be seen and justified this assumption on the undulations, which were seen above bodies heated by the sun. Air was a fluid element, elastic and mobile, that owed all its mobility to the fire contained in it, and that after its removal air would assume a concrete form. Air was necessary for fermentation to occur; he assumed that champagne was stored in closed bottles to stop the process; opening of the bottle generated foam because contact of the liquid with air reinitiated fermentation (Secrétan, 1943).

The section of his lectures entitled *règne mineral* is very important because it represents Rouelle's theory of matter, the nature of chemical combination, and certain physical phenomena such as color and odor. As a chemist, Rouelle believed, contrary to Newton, in the existence that carried qualities. He believed that phlogiston was the principle of color. White meant absence of color (contrary to Newton who believed that black was due to the absence of color). For Rouelle, black was simply a very deep blue. He opposed the opinion of physicists regarding odors: "Les Physiciens ont imaginé que les odeurs se distribuaient comme la lumière; mais ils se sont trompés, car le principe de l'odeur est un corps composé qui ne peut s'enlever en l'air qu'à la manière de la poussière, et qui suit toujours les différents mouvements de l'air" (Scientists believe that odors distribute themselves like light, but they are wrong because the principle of odor is a compound body that can elevate in air only the way dust does, following all the time the movements of air) (Mayer, 1970).

Rouelle rejected the opinion sustained by Benoit de Maillet (1656-1738) and Bouffon that the sun was composed of molten glass and crystal. According to Rouelle it was made of metals; the slag explained its spots. Gold had to be a solar component because it was indestructible and resisted high temperatures.

The introduction of the *règne mineral* included a long essay about geology and the history of the Earth. After enumerating the metals and semi-metals (antimony, bismuth, zinc, and cobalt) Rouelle stated that these substances were not mixed at random in the inside of the earth, on the contrary, they were organized in a very symmetric manner. In order to justify this assumption he postulated a general theory of geological stratification, in which they were two general strata, the *terre ancienne* and *terre nouvelle*, distinct from each other in their composition and the methods of their formation. The *terre ancienne* was the primitive earth that had always existed; the *terre nouvelle* was a layer that had reorganized as a result of the geological alterations that had taken place in the planet. Although the *terre ancienne* had also suffered alterations due to volcanic activity, the crystalline structure of rocks had remained unchanged. The *terre ancienne* was dominated by volcanism, the *terre nouvelle* by the dissolution of minerals and their transport in saline form to the sea.

The most curious aspect of Rouelle's theory was the assumption that a large body of water was present in the center of the earth, which activated most of the transformations; together with the central fire it caused all the changes that took place in the interior of the globe.

Sometime after 1763, probably influenced by the work of Johann Gottlieb Lehmann (1719-1767) and by the observations of his pupils, Rouelle modified this theory to include a third series of strata, referred to simply as "un travail intermédiaire". In this new classification the *terre ancienne* consisted of massive unstratified, granitic deposits; the intermediate strata contained bitumens and debris of various kinds; and the *terre nouvelle* was a complex structure composed of horizontal layers deposited by slow sedimentation (Rappaport, 1960).

By far the longest of the three major divisions of the course, the *règne mineral* included experiments on bitumen, acids (sulfuric, nitric and hydrochloric), the so-called *semi-metals*, and metals. In this section Rouelle discussed the composition of metals, the purification of metallic ores, the formation of salts, and the different classes of salts.

The final section of the course was devoted to the discussion of alchemy. As a disciple of Becher, Rouelle did not question entirely alchemy. He wrote that "it is to reason poorly to conclude that because it is impossible for us to reproduce a plant, an animal, that it is impossible to reproduce a metallic substance which is without organization and without life." These ideas were consistent with those about the formation of metals. In theory he considered possible to combine the three principles of which metals consisted in the correct proportions to produce gold: "We understand the inflammable principle and the vitrifiable principle. If we understood the mercurial principle as well, we would perhaps succeed more easily in imitating the combination of gold."

Together with his course in chemistry, Rouelle gave lectures in pharmacy in which he specified, "There should be a distinction between the pharmaceutical production process and chemistry. Without the latter, the former makes only chance combinations and mixtures, which, far from reaching the desired end, are often very harmful. It is chemistry that lays the foundations for all good pharmacy. It is from the exact knowledge of analysis that principles are deduced." His pharmacopoeia included some wild (today) recommendations; for example, Dippel's oil (oil extracted from the deer corns and distilled *sixty* times) was useful in the treatment of epilepsy and hysteria; *spiritus magnanimilalis* (ants' acid, formic acid) was an excellent aphrodisiac; sulphuric acid well diluted in water constituted a kind of lemonade (!) (Secrétan, 1943).

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Rouelle became a pharmacist by privilege and not by right. In 1750 the *Compagnie des Apothicaires de Paris* (Apothecary Guild of Paris) was so anxious of adding a man of such high repute to its ranks that they offered him membership under any conditions that Rouelle might think fit. Rouelle rejected admittance under these terms and submitted himself to all the required exams for admission, which he passed without difficulty. This appointment enabled him to add an apothecary shop to his laboratory in the rue Jacob near *La Charité* (his seven years with Spitzley had not entitled him to an apothecary's license, which required four years *apprentissage* and six years *compagnonnage;* he could only use the secondary title of *apothicaire-privilégié*).

In 1750 Rouelle was also elected to the Royal Academy of Sciences of Stockholm and to the Electoral Academy of Erfurt.

During the 1740's and 1750's the French government sought after Rouelle's scientific talents. When the position of apothecary to the king became vacant upon the death of Boulduc in 1742, the Duc of Vrillière offered it to Rouelle, who declined this lucrative appointment. He later accepted the position of *inspecteur de la pharmacie* at the Hôtel-Dieu (a public hospital), because these duties did not interfere with his other activities. When, in 1744, a cattle plague was causing much damage in France, Rouelle was appointed to a committee of scientists to study the disease and find its cure. In 1753 the Minister of War commissioned Rouelle examine a new procedure for the manufacture of saltpetre. The pertinent tests were done at the Arsenal and Rouelle concluded that the procedure was inadequate and that it would result in the degradation of gunpowder in the cannon itself. In 1754 Rouelle and his brother Hilarie-Marin were asked by the minister of finance to examine the alloys of gold used in minting coins (Cap, 1842).

Rouelles activities during the last fifteen years of his life remain obscure. Although he continued to teach, the exhaustion caused by the last two missions debilitated his health and eventually led to his resigning to his classes and his position at the Jardin du Roi, in favour of his brother Rouelle *le cadet*. After that he languished into a life of much physical pain, he lost the use of his legs and was transferred to Passy were he died on August 3, 1770, at the age of 67.

After his death, efforts were made to edit and publish his lectures. Various sets of notes were collected by his youngest brother Hilarie-Marin and by Darcet and carefully collated, but the project was never completed. Rouelles poor publication record and the failure to publish his notes in the form of a textbook led to his descent from relative prominence to obscurity. With the acceptance of the new chemistry of Lavoisier, Rouelles theories rapidly became obsolete and hardly worth publishing. Nevertheless, to this credit it must be said that Rouelle bridged the gap between the old chemistry and that arising from the chemical revolution, which culminated in the work of Lavoisier.

Rouelle was married to Anne Mondon, who assisted Rouelle le cadet in maintaining the apothecary shop after her husband's death. They had twelve children, but only two (a son and a daughter) were alive at the time of his death. In 1771 his daughter Françoise-Julie married Darcet, a noted chemist and one of Rouelle's pupils.

Salts

During a long time in the development of chemistry the concept of salt remained obscure and ill defined. For the ancients, salts had the two characteristics dominant in marine salt: taste and solubility in water. These ideas about salts remained extant during the Middle Ages and on their basis completely different compounds such as marine salt, rock salt, ammonia salt (ammonium chloride), nitre salt (potassium nitrate), and vegetable salt (potassium tartrate) were grouped together. Vitriols (sulfates) were placed in a different class although they possessed the two essential characters of a salt (taste and solubility); some chemists did not consider them even as salts.

The qualification of solubility in water led to the inclusion in the category of salts compounds having the most opposed properties, such as acids, and animal and vegetable matter. According to Becher, salt represented that which was fixed and incombustible, and in a certain manner, that which was mineral in bodies. Stahl defined salt in various confusing and contradictory terms and considered salts, acids, earths, and alkalis, to be analogues, and the same as Becher, he included under this term *all* chemical combinations. He accepted the analogy between acids, salts, and alkali, and thought that one could be converted into the other. In addition, he considered that salts were in some way, a stage in the transformation of alkalis into acids. According to Stahl and the ancient chemists, sulphuric acid was the only substance saline by itself, a unique saline principle that by the more or less intimate union that it achieved with other *non saline* substances, it was able to form a large number of *saline* substances, less simpler in structure. Although sulfuric acid was the only substance saline, it was a secondary principle, formed by the intimate contact between the two primitive elements of water and earth. Hence, salts should present properties intermediate between these two components. Thus, sulfuric acid had a density larger than water and smaller than earth. Crystallization of sulfuric acid at a temperature above that of melting ice (because of hydrate formation) was due to the tendency of the earth to solidify. Another proof of its resemblance to water was the fact that sulphuric acid was limpid and colorless.

A curious detail is the way salts were visualized. According to Sénac an acid salt was an assemblage of rigid particles, oblong and pointed at both ends. Why was this so? Acid salts were capable of dissolving most solid bodies, hence its particles had to be very rigid and sharp. An acid would burn the tongue without roughening it like an acrid salt, hence its particles were rigid and piquant. An acid always penetrated bodies easily: hence it was necessary that its two extremes be pointed and sharp. Contrary, alkalis were composed of earthy solid particles whose interstitial pores were so shaped as to admit entry of the spike particles of acid. Lémery postulated that, for reaction to occur between a particular acid and alkali, there had be an appropriate relationship between the size of the acid spikes and alkaline pores. Alkalis were those substances that reacted with acids producing ebullition or effervescence. The latter phenomenon was a result of the shape of the respective particles; when the sharp acid particles penetrated into the pores of the alkaline particles, they met with resistance with the resulting effervescence (Secrétan, 1943).

Rouelle published five memoirs, three if them dealing with the nature of salts. The first memoir (Rouelle, 1744) appeared at a time when there existed at least three schools of thought about the nature of salts. Chemists had considered salts under every possible point of view, without looking for the basis of a classification. Georg Stahl (1660-1734) was interested in the form of their crystals, Lémery about their solubility, and Giovanni Domenico Guglielmini (1655-1710) about the phenomena and laws of their crystallization. Despite the attacks of Boyle, the notion of salt as one of the three spagyric (iatrochemical) principles (*tria prima*) had not completed vanished from chemistry. According to Boyle substances should actually be classified in three groups: acids, alkalis, and neutral salts or solutions. A second theory, also associated with Stahl and his disciples, claimed that salt was a compound of water and one or more of three kinds of earth principles. Others spoke of the shape and motion of constituent particles, which determined the relative acidity or alkalinity of salts (Rappaport, 1960).

According to Rouelle, during the slow evaporation of the water from an aqueous saline solution, the salt molecules, invisibles in the solution, unified and reappeared in a form constant and typical of each species of salt. The salt not only assumed a constant form, but also retained an amount of water, and required a period of time, short or long, to crystallize. Rouelle gathered all this information and for the first time he found a principle for their methodical division. His original classification was based on six sections in the family of neutral salts, each section defined by their crystal form. Each section was further divided into genera and species; the acid gave the gender and the base the species. The sections were characterized by the different crystalline forms and by the time required or evaporation during which they yielded crystals, which were larger and more perfect. It was also based on the singular structure of the crystals, the manner in which they agglomerated, and the growing that took place immediately after crystallization. Thus, the first section included all the salts that crystallized in lamina; the first genre of this section contained all the salts of vitriolic acid, and the different species contained all the vitriols having a fix or volatile alkali, earths, or metallic substances.

Rouelle's six sections were the following:

1. Common salts (*moyens*), whose individual crystals were shaped as lamina or very thin flakes.
2. Neutral salts, having crystals shaped like cubes, cubes with broken angles, and pyramids having four or six faces.
3. Salts having crystals shaped as tetrahedral, pyramids, parallelepipeds, rhomboids, and rhomboidal parallelepipeds, with their angles being cut differently.
4. Salts crystallizing as flattened parallelepipeds, with their extreme ending in two surfaces having opposite inclination, such that they formed pointed and acute angles with the large faces of the parallelepiped.
5. Salts having long and thin crystals, looking like needles, prisms, or columns with faces shaped differently.
6. Salts having crystals shaped like very small needles or undetermined shapes.

We can see that Rouelle recognized the existence of neutral salts (*sels moyen*), as he called them, which we now call normal salts, in which acid and base were exactly saturated by one another. Their neutrality was demonstrated by the fact that they did not change the color of an indicator then in common use, namely, syrup of violets. In 1754 Rouelle read another memoir (Rouelle, 1754) about salts in which for the first time he distinguished between acid salts (*excès d'acide*), normal (sel moyen) or perfect salts (sel parfait), and salts having an excess of base (*très-peu d'acide*) and thereby providing his answer to the controversial question of the nature of acid, alkali, and salt. In the first ones, there was an abundance of acid, which was not admixed but combined; this combination had limits, which were like a second point of saturation "au delà duquel les sels ne pouvaient pas absorber une nouvelle quantité d'acide" (the point after which the salts could not absorb more acid), a crude statement of the law of constant proportions. He gave as examples, potassium bisulfate, mercurious sulfate, calomel, and sublimé corrosif (corrosive sublimate, $HgCl_2$). For the latter, which Rouelle regarded as having an excess of acid, the second saturation point corresponded to the point in which the salt acquired the property of sublimating or crystallizing.

In this memoir Rouelle stated in clear terms the definition of neutral salts presupposed in 1744: "J'apelle sel neutre, moyen ou salé tout sel formé par l'union de quelque acide que ce soit, minéral ou végétal, avec un alcali fixe ou volatil, une terre absorbante, une substance métallique ou une huile. Je joins ensemble toutes les substances salines, et je les unis en une seule classe, parce qu'elles ont des figures et des propriétés qui leur sont communes; et comme on le verra par le suite, ces sels si on n'a égard qu'aux seuls phénomènes de la cristallisation sont susceptibles d'une division méthodique" (I give the name neutral salt to every salt formed by the union of any acid, mineral or vegetable, with a fixed or volatile alkali, an absorbing earth, a metallic substance, or an oil. I group together all saline substances in one single class because they have common shapes and properties.).

Rouelle restricted himself to applying the term salt to those crystallizing products in which any acid was joined to an alkaline base, earthen or metallic. There were simple and compound salts. Benzoic acid was a simple acid and the fixed alkalis were simple alkaline. Salts properly, formed by an acid and a base, were compound salts (*sels composées*); Rouelle named them *sels neutres*, because they participated simultaneously of a base and an acid. Finally, there were natural salts and artificial salts. Johann-Rudolf Glauber (1604-1668) had provided with his *sel admirable* (sodium sulfate), the first example of the latter category.

Salts with the minimum proportion of acid included, for example, silver chloride and calomel, but Rouelle advanced chemical theory in considering these substances as salts, since they had not previously been so regarded because of their slight solubility.

The first memoir about salts was followed by another one describing specifically to the crystallization of marine salt (Rouelle, 1745). Here he determined precisely the degree of evaporation needed in order to obtain small crystalline pyramids. The crystals were heavier than water and precipitated without adherence of air.

Rouelle's new classification of salts in three classes, according to equilibrium or the predominance of the composing compounds was, without doubt, another important step forward in the development of chemistry, after the publication of Étienne-François Geoffroy's (1672-1731) tables of affinities. His memoir contained, in addition, a series of generalities applicable to each class, as well as a multitude of experimental facts. His classification was attacked by several of his contemporary chemists. Antoine Baumé (1728-1804), for example, was one of the most opinionated ones because he had recently claimed that in salts of the first class, the acid was actually present in a *free state* and not combined, and thus could be separated by washing, a statement that was afterwards rejected by the experimental facts.

Rouelles classification was the first to be applied simultaneously to natural products and manufactured ones. It was clearly a classification borrowed from mineralogy, although it must be recognized that it put the latter on a more rational basis, which mineralogy adopted later, that of organizing the mineral species according to their chemical composition.

Turpentine oil

In 1747 Rouelle read a memoir that attracted wide interest (Rouelle, 1747). It was well known that esprit of nitre (nitric acid) was capable of igniting essential oils, a phenomenon with potential industrial and military uses. Many years before Olaüs Borichius (1626-1690) had proposed igniting turpentine oil using spirit of nitre, but because his actual procedure was poorly described or kept secret, it had been impossible to reproduce. Chemists, such as Johann Konrad Dippel (1673-1734), Frederick Hoffmann (1660-1743), and Geoffroy, had succeeded in igniting the oil but only after adding vitriolic acid to the nitric acid. Rouelle investigated the problem and found that for ignition to occur, it was necessary first to carbonize the oil with a little of nitric acid; sudden addition of another dose of esprit of nitre resulted in inflammation. This procedure was easily extended to fatty oils. Rouelle found that addition of a small amount of vitriolic acid to the nitric acid did the trick, because it caused dephlegmation of the mixture. As he remarked, this was necessary "pour le déphlegmer, en lui enlevant un certaine proportion d'eau, puis il déterminait l'inflammation, par l'addition d'une petite quantité désprit de nitre" (In order to dephlegmate by eliminating a certain amount of water and then inflammate by adding a small amount of nitric acid.). Clearly, Rouelle was using the hygroscopic property of sulfuric acid to dehydrate the nitric acid.

Vegetable chemistry

Of the different branches of chemistry, the one related to mineral chemistry was obviously the most advanced. Johann Kunckel (1630-1703) had spent more than sixty years investigating metals and acids. In England there had been many useful applications of chemistry to the arts and manufacturing and the work of the alchemists had contributed substantially to the knowledge of mineral substances and their combinations.

This was not the case with plants because thus far only medicine had attached a certain value to the knowledge of their composition. Lacking special methods, chemists had applied to plants the same testing methods used for minerals, that is, distillation in an alembic, incineration, lixiviation, and the evaporation of liquids. These procedures accounted well for the amount of *phlegme*, *d'huile*, *d'esprit*, *de sel volatile*, and *of caput mortuum* (solid residue) obtained, but said nothing about composition. It was found that poisonous plants and beneficial plants generated the same products; for example, wheat yielded the same products as aconite or hemlock, so that this mode of analysis did not allow differentiating between food and poison.

Around the same time Rouelle performed his great works on plant chemistry. He devoted himself to define, to distinguish, and to classify the many materials that could be extracted by means of much analysis. He named these materials, for the first time, *principes immédiats des végétaux* (basic vegetable principles). He did not publish his results but incorporated them in his lectures. According to Cap, Rouelle may well be considered the father of vegetable chemistry (Cap, 1842).

Embalming

Rouelle also published a memoir about embalming (Rouelle, 1750). The Comte de Caylus, a historian, asked Rouelle to investigate the embalming process employed by the ancient Egyptians, as well as to identify the substances, which were used in the process. As background material he provided Rouelle with a copy of Herodotus' writings (Rawlinson, 1928) on the subject, together with some mummy specimens. After inspecting the mummies and reading Herodotus' description of the process, it became clear to Rouelle that the Greek historian had misunderstood the techniques used by the Egyptians; his errors stemmed from the fact that he had written what he had heard, without actually having been present during an embalming process.

For example, Herodotus claimed that the Egyptians used first *Cédria* (a liquid bitumen similar to pissasphalt and having a strong smell) to dissolve the intestines, and then natron (natural sodium carbonate) as means of conservation: "and take out the whole contents of the abdomen, which they then cleanse, washing it thoroughly with palm wine, and again frequently with an infusion of pounded aromatics. After this they fill the cavity with the purest bruised myrrh, with cassia, Then the body is placed in natrum for seventy days, and covered entirely over" (Rawlinson, 1928). Rouelle demonstrated that the Egyptian procedure was actually the opposite: first they emptied the large visceral cavities by surgical means, and then they injected into the cavity an alkaline solution of natron, a powerful alkali, with the purpose of washing and dissolving the soft parts. Once these operations were finished, they smeared the body internally and externally with Cédria, then filled it with resins such as fuchsin, balsam of Judea, and other aromatic substances, followed by wrapping with bandages. Exposure of the wrapped body to air or to an artificial drying process gave it the property of indefinite conservation.

Rouelle used his findings to duplicate successfully the traditional art of embalming and prepare some specimens for the Comte.

Conclusion

To the casual modern reader, used to judge the work of a scientist by the number of his publications and not by the quality of his teaching, Rouelle will appear as a very minor figure in the development of science. Rouelle should actually be judged against the scientific background and standards of his time. He did much laboratory research but for his own reasons he preferred to report his results directly to his students in his classes, instead of publishing them. Very few scientists can show to their credit a list of students as amous as those attending Rouelles lectures, particularly when these were not part of a curriculum. Rouelle was able to communicate to his students the enthusiasm he felt for chemistry; this seed germinated and catalyzed many of the most fertile minds of France of his time.

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