

RESEÑA BIOGRAFICA

Antoine François de Fourcroy.

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RESUMEN. Antoine François de Fourcroy (1755-1809), un médico convertido en químico, representó un papel clave en la investigación, enseñanza y aplicaciones industriales de la química durante las diversas etapas de la Revolución Francesa. El combinó sus conocimientos de medicina y química para adelantar la relación entre esta última y los fenómenos fisiológicos y patológicos. Es considerado el fundador de la patología moderna. Gran parte de su investigación posterior la realizó en colaboración con Vauquelin; juntos contribuyeron en forma significativa a la química vegetal; fueron los primeros en aplicar el análisis cuantitativo a la química orgánica, en mostrar la diferencia entre el éter y el aldehído acético, en analizar a fondo la química de los cálculos urinarios y en descubrir la urea. Fourcroy fue partidario de la Revolución y jugó un papel decisivo en el establecimiento de un nuevo sistema educacional, así como en la fundación de las más importantes instituciones de educación superior, tales como las Escuelas Politécnica y de Medicina.

ABSTRACT. Antoine François de Fourcroy (1755-1809), a physician turned chemist, played a major part in the research, teaching, and industrial applications of chemistry during the different stages of the French Revolution. He combined his knowledge of medicine and chemistry to advance the connection between the latter and physiological and pathological phenomena. He is considered the originator of modern pathology. Most of his later research was done in collaboration with Vauquelin, with whom he made significant contributions to vegetable chemistry; they were among the first to apply quantitative analysis to organic chemistry, to show the difference between ether and acetaldehyde, to analyze in depth the chemistry of urinary calculi, and to discover urea. Fourcroy supported the Revolution and took a leading part in the establishment of the new education system in France, as well as in the foundation of the most important institutions of higher learning, such as the *Écoles Polytechnique* and *de Médecine*.

LIFE AND CAREER¹⁻³

Antoine François de Fourcroy (Fig. 1) was born on June 16, 1755, one of the twelve children of Jean-Michel de Fourcroy (1710-1783) and Jeanne Laugier. His mother passed away in 1762 when Fourcroy was seven years old.

In 1747 his father acquired the position of apothecary of the Duc d'Orléans left vacant by the resignation of Motte, the previous owner, a purchase that carried with it the right to open and operate a pharmacy. This business was not very successful; the Apothecary Guild, always fighting against druggists and privileged, eventually succeeded in closing the pharmacy.



Fig. 1. Antoine François de Fourcroy (1755-1809). (By permission of Edgar Fahs Smith Collection, University of Pennsylvania Library).

At the age of nine Antoine François entered the *Collège d'Harcourt* as an external student; there he did not show any particular attraction or ability for science. Ambroise Marie François Joseph Palisot de Beauvois (1752-1820), his classmate and close friend, wrote that Antoine François liked memorizing the finest passages from poets and dramatists and could always amuse his friends by imitating famous actors; it was the general opinion that his future was in the theatre. In practice, Fourcroy's declamatory abilities would later on find expression in his teaching and political career.

The economical situation of his father worsened and not being able to keep his son in the *Collège* he interned him, at the age of fifteen, in the home of a writing master where he succeeded in such a way that within a year he was able to occupy a place of copying clerk in the Bureau of the Chancellery. In the evenings he would do copy work or give writing lessons to earn his living.

With the help of the famous anatomist Felix Vicq D'Azyr (1748-1794), a friend of his father, he was able to enter the *Faculté de Médecine* in Paris. Fourcroy obtained his *Maître-ès-Arts* in 1755 and the Bachelier in 1778. In 1778 he defended successfully his first *Thèse de License* (*Thèse cardinale d'hygiène*), "*De Utilitate Effluviarum Elasticorum Gas Dictorum ad Tuendam Sanitatem*" (11 pages), dealing with the therapeutic value of breathing various new gases. In 1779 he passed his theses of physiology (*Thèse quod libetare*): "*De Anatome Comparata*" (32 pages) and medico-chirurgical: "*De Nova Laryngoto-*

miae Methodo" (8 pages). The same year he defended his last thesis (*Thèse de Pathologie*): "*De Usu et Abusu Chemiae in Medendo*" (8 pages); which was rejected on the grounds that it carried doctrine errors, injuries against the Faculty, and a tendency to quote excessively the works of Jean Baptiste Marie Bucquet (1746-1780) and Pierre Navier (1712-1779) (both members of the *Société Royale de Médecine*, a group in bitter competition and argument with the *Faculté de Médecine*). In 1780 Fourcroy defended a new thesis "*An ut in Febribus Intermittentibus ita in Plerisque Morbis Periodicis Salubris Kinoe Usus*" (seven pages) and passed his final exam. With the help of a collection organized at the *Société Royale de Médecine*, he was able to pay the 6 000 livres required to obtain his brevet as a doctor (Note 1).

Fourcroy did not practice medicine for long, he became a chemistry student of Jean-Baptiste Bucquet (1746-1780) and afterwards popularised the rudiments of this science in many institutions of free learning. Eventually Bucquet became very ill and requested from Fourcroy to take over the private course in chemistry (*Histoire Naturelle et de Chimie*) he was giving. Fourcroy accepted and prepared for this purpose a set of notes entitled "*Leçons Élémentaires d'Histoire Naturelle et de Chimie*", in two volumes, the first one with 672 pages and the second with 848 pages.⁴ The course started in 1782 and consisted of seventy lectures of chemistry and natural history; it ended in 1791 when most of the private courses in Paris ceased.

On February 23, 1784, on the strong recommendation of George-Louis Leclerc Buffon (1707-1788) he was appointed to the Jardin du Roi (afterwards, the *Muséum d'Histoire Naturelle*), to occupy the chair left vacant by the death of Pierre-Joseph Macquer (1718-1784).

Fourcroy belonged to the *Académie des Sciences* and the *Académie de Médecine*. In 1776, under the protection of Vicq d'Azyr, he created the chemical section of the *Société Royale de Médecine*, which was given the task, among others, to deter-

mine the chemical composition of new medicines. Fourcroy had the talent for identifying the nexus between his experimental results and their physiological and pathological relevance, and also of their application to hospital management and basic teaching. He became involved in the various means whereby chemistry could eliminate medicine.

Fourcroy was also a politician and an executive and took active participation in the different stages of the Revolution. In 1792 a group of literary men founded the *École Athénienne*, of the same category as the *Athénée* or Republican Lyceum. At the *École* Fourcroy taught chemistry and on November 6, 1793, he initiated the formation of a depuration committee charged with "cleaning" the *Lycée* of emigrants and counter-revolutionaries. Antoine-Laurent Lavoisier (1743-1794) was one of the members who were expelled. The expulsion identified him as a counter revolutionary against the government committees, just at the time when the General Farmers were under brutal attacks. Three weeks later, in November 28, Lavoisier was put in jail and sent to the guillotine on May 8, 1794. Fourcroy denied the accusation that he was partly responsible for Lavoisier's execution, although he did not openly exert himself in what he probably realized would be useless efforts to save his colleague; he was responsible for saving the life of Jean Darcet (1725-1801).

Fourcroy had a senior rank in the Freemasons; he belonged to the Club des Jacobins and was also the president of the latter. During the voting purge of the Club, the 8th of December 1793, he excused himself of participating because he was poor and ignorant and had to work to feed his father and sisters. Appointed by the Committee of Public Health, on April 9, 1793, with other leftist scientists, he occupied about questions related to gunpowder, arms, and treatment of bronzes from bells, destined to the manufacture of coins, etc. After Maximilien Robespierre's (1758-1794) fall he became of the principal re-

organizers of education. He was fourth substitute Deputy for Paris to the National Convention; on July 25 1793, he succeeded Jean-Paul Marat (1743-1793), who had been murdered by Charlotte Corday (1768-1793).

In 1793 he was a member of a commission charged with the establishment of a national medical school and he presented the report to the Convention. Two important consequences of this report were the laws re-establishing the legal necessity to hold a diploma in order to practice medicine and creating the *Écoles de Santé*. The *École de Santé*, later the *École de Médecine*, was opened in Paris in January 1795, two smaller colleges being opened in Strasbourg and Montpellier. The laws merged the teaching of physicians and surgeons and imposed a basic culture of science, theory, and experiment. It underlined the need for anatomical dissection and for an active participation in hospital care and outpatient clinics, which also led to an increase of intellectual activity.⁵

Fourcroy was appointed *Conseiller d'Etat* by Napoleon, then director of public instruction. In 1794 Fourcroy participated in planning the *École Centrale des Travaux Publiques*, which in 1795 became the *École Polytechnique* and he was one of the professors. In 1801, when he was made Consul by Napoleon, he organized public instruction in chemistry; during 1802-1808 he was Minister of Public Instruction. He prepared during five years the regulations (*reglement*) of the Imperial University. He expected to be nominated to the newly created rank of *Grand Maître*, (Grand Master, Rector of the Imperial University) but Napoleon passed him over and nominated Louis de Fontanes (1757-1821), President of the Legislative Body and the lover of Elisa Bonaparte. It is said that this snub caused him much grief; affected by a heart disease, he passed away suddenly on December 16, 1809; the same day he was nominated senator and Compté of the Empire. He is buried in the Père Lachaise cemetery, next to his wife.

1. In order to be admitted to the Faculty of Medicine it was necessary first to obtain the *Maîtrise ès-Arts* (Master of Arts) of the Université de Paris, then at the Faculty, to obtain successively the degrees of *Bachelier* (bachelor), *Licencié*, *Docteur*, and finally *Docteur Régent* that gave the right to teach at the Faculty. To become a *Bachelier* it was necessary to pass a qualifying exam; followed by two years of study and the approval of four theses to obtain the degree of *Licencié*. Approval of the four theses led to the award of the degree of *Docteur*. The total fees for obtaining all these degrees were about 6 000 livres.

His death represented a loss to science and to education; Jacques Thénard (1777-1857) replaced him at the Institute, André Laugier (1770-1832) at the *Muséum d'Histoire Naturelle*, Louis Nicolas Vauquelin (1763-1829) at the *Faculté de Médecine*, and Joseph-Louis Gay-Lussac (1778-1850) at the *École Polytechnique*.

In June 1780 Fourcroy married Anne-Claudine Bettinger (1764-1838), the daughter of an official in the Ministry of War; they had two children; the oldest, Nicolas (1786-1813), graduated from the *École Polytechnique*, became Officier de la Garde, and was killed in 1813 during the battle of Lutzen (May 2, 1813); the daughter (1782-1839) Apolline married Alexandre Floucaud, *Receveur Général de la Corrèze*, from which descend all the present members of the family. Fourcroy used part of the dowry to buy Bucquet's laboratory and to return to the *Société de Médecine* the money he had received to pay he 6 000 livres to obtain his brevet as a doctor. Fourcroy divorced his wife in 1799 and on January 17, 1800, married Adélaïde Flore Belleville (Madame de Wailly, the widow of the architect Charles Wailly) on January 17, 1800; they no children.²

The 1785 reorganization of the *Académie* left vacant an associate chemistry slot, to which Fourcroy was elected on May 11 1785. He was then thirty years old.

Fourcroy published more than two hundred memoirs, alone or together with other chemists, on the subjects of mineral salts and animal and vegetable substances. Many of the publications were on medical subjects; Fourcroy can be considered the originator of modern pathology. Georges Cuvier (1769-1832) wrote that many of these memoirs as "*semblent n'exiger que de l'assiduité*" (seemed to require only assiduity) and that Fourcroy "*avait des idées en general étendues que profondes...etc.*" (he had ideas that that were more extended than profound)." "His principal collaborator was Vauquelin. He also published a few memoirs with Louis-Jacques Thénard (1777-1857) but he was not considered to be one his teachers.

Thomas Thomson (1773-1852), his contemporary, says that the "prodigious reputation that Fourcroy enjoyed during his lifetime was more due to his eloquence than to his eminence as a chemist. The general opinion is that the experiments were made by Vauquelin, but that the papers themselves were drawn up by Fourcroy."

The relation between Fourcroy and Vauquelin came about by accident. In the beginning of his career Vauquelin was working as a helper in the pharmacy owned by Chéradame, a relative of Fourcroy. Chéradame promptly recognized Vauquelin's abilities and introduced him to Fourcroy, who offered the young man to become his *preparateur*, a position that provided lodging, food, and paid one hundred livres per year. From there Vauquelin went on to become the best analytical chemist of his time and a member of the *Académie des Sciences*. Fourcroy and Vauquelin also collaborated in a commercial venture, a small factory, which they set up for the manufacture of chemicals. Kersaint has given a detailed account of this industry.⁶ Vauquelin never forgot the debt to his master and also extended his appreciation to his family. He remained single all his life and after Fourcroy passed away he asked his sisters, M^{mes} Leabilly and Guédon, to move in to his house and become his home keepers. He assigned them a large part of his apartment as living quarters and lived modestly in the remaining. The two sisters managed his home and took care of him during the many times he was very ill, until his death.⁷

As discussed by Kersaint² Fourcroy's teaching and research abilities have been highly praised by some and highly criticized by others. Fourcroy spoke with ease; he rapidly became famous by his eloquent style that also reflected in his books, although he appeared always solemn and excessively dogmatic. Jean-Louis Rieu (1788-1868), a foreign student at the *École Polytechnique*, described in his memoirs the teachers of this *École*. Regarding Fourcroy he wrote: "*Nous eûmes the lessons of the famous Monge, founder*

of the École about the aerienne perspective; quoique ce ne fût que pour la montre, comme celles de Fourcroy, il y avait toute la difference du vrai savant au charlatan" (We enjoyed the lessons given by the famous Monge, founder of the school of spatial geometry although they were not for exhibition purposes like those of Fourcroy, they had all the difference between a true sage and a charlatan).⁸

HONORS AND POSITIONS

Fourcroy received many honors for his contribution to science, industry, and the Nation. During the blockade of France he played a part in organizing national industries, especially of saltpetre, which later rendered the country independent of imports. He was a member of *Société Royale de Médecine* (1780), Professor of Chemistry of the Animal Kingdom at the *École Royale Vétérinaire d'Alfort* (1783-1787), Professor of Chemistry at the *Jardin du Roi* (1784), Professor at the *École de Santé* and *École Polytechnique* (1795); member of the *Académie des Sciences (associé chimiste, 1785)*, member of the *Société d'Histoire Naturelle* (1790) and President of the same (1790); member of the *École Libre des Pharmaciens* of Paris (1797); resident member of the *Académie d'Agriculture* (1798); member of the Royal Academy of Stockholm (1801), member of the Academy of Göttingen (1802); and co-founder and editor of *Annales de Chimie* (1789-1809). He was also a member of the *Lycée des Arts* and one of its founders, and Professor of chemistry at the *Collège de France*. In 1783 he as appointed as one of the twenty-eight *Censeurs Royaux* (Royal Censors), for works on natural history, medicine and chemistry. He remained in this position until censorship was abolished during the Revolution (Note 2).

His public and political activities reflect not only his eloquence and political ability but also the fast changes that took place in France during the period of the Revolution: Fourcroy was *Electeur* (Elector) to the Constituent (1789); delegate of the *Académie des Sciences* to the

2. Censorship began in Paris in the thirteenth century, before the invention of printing. The assignment of printing rights was under the jurisdiction of the Paris Faculty of Theology. As the book trade increased the Crown increased the number of censors from four in 1653 to about eighty in 1750. The censors possessed specialized talents other than theology, were assigned to subjects consistent with their training, and the Crown paid for their services.

Bureau de Consultation des Arts et Métiers (1792); Fourth Substitute Deputy to the National Convention (1792); Deputy to the Convention in replacement of Marat (1793); President of the Club des Jacobins (1793); member of the Committee of Public Health (1794-1795); member of the Committee of Public Instruction (1795); member of the *Conseil des Anciens* (1795); *Director of the Muséum d'Histoire Naturelle* (1799); Councillor of State at the Interior Section; General Director of Public Instruction (1802-1808); member of the *Legion d'Honneur* (1803, promoted to commandant in 1805); Councillor of the State for life (1807); General Director of Mines (1808); and Count of the Empire (1808).

The *façade of the Hôtel de Ville* in Paris has 108 statues of important people born in Paris, the one of Fourcroy, sculpted by Franceschini, is located on the main *façade*.

SCIENTIFIC CONTRIBUTION

The scientific work of Fourcroy was very extensive; in addition to a large number of books, speeches and reports, he published over 150 memoirs in which is name was associated with Vauquelin. Vauquelin is the scientist he discovered, educated, stimulated, and was his very close friend. The results of the co-operation with Vauquelin have been the subject of much criticism regarding the contribution of both partners, some well-known scientists such Michel Eugène Chevreul (1786-1889), Paul Thenard (1819-1884), and Louis Jacques Simon (1867-1925) having openly insinuated that the actual work was done by Vauquelin and that Fourcroy simply wrote the papers.² Others, like Cuvier have said that Fourcroy proposed and developed the ideas and Vauquelin executed and controlled them.¹

Fourcroy's first memoirs were published by himself in the form of a book entitled *Mémoires et Observations Chimiques*⁹ and destined to serve as a continuation of the notes for his course. It contained all the experiments he had performed between 1776 and 1784 on the action of alkalis on iron salts; on marsh gas and other inflammable vapors; on the detonation of potassium nitrate and gunpowder; on the decomposition of potassium sulfate by metals; on the reagents used for the analysis of mineral waters, on chemical affinity, on an improved Lavoisier's gas meter, etc., etc. The book was

published under the privileges of the *Académie Royale des Sciences* and the *Société Royal de Médecine*.

In a section of the book, entitled *Mémoire Sur l'Art de Faire des Recherches de Chimie et Sur Celui d'Observer et de Décrire les Phénomènes Chimiques* Fourcroy listed the three axioms that a chemist should abide for when doing research:

(1) "*Observer les phénomènes sans se laisser détourner de la réalité, même si ceux-ci ne sont pas conformes aux hypothèses de départ. Il n'y a que l'expérience qui compte*" (Observe the phenomena without being carried away from reality, even if they do not conform to the initial hypotheses. Only experience counts.).

(2) "*Décrire les expériences avec toute la précision nécessaire, en tenant compte des différents facteurs qui interviennent, de façon qu'un autre chimiste puisse les reproduire*" (make all the experiences with the necessary care, taking into account all the intervening factors so that another chemist may reproduce them).

(3) "*On ne doit considérer les résultats comme valables que si d'autres chimistes opérant suivant le même processus arrivent au même résultat*" (The results should not be considered valid unless other chemists operating under the same procedure obtain the same results.).

Due to the extensive nature of Fourcroy's activities only a few of his most important contributions will be discussed.

1. Phlogiston

The phlogiston theory originated around 1700 from the ideas and experiences of Joachim Becher (1635-1682) and consolidated with George Ernst Stahl (1660-1734). Its basic tenets were based on the fact that a large number of chemical substances were combustible; some like carbon and sulfur burned with a flame and released a large amount of heat, while others, like the metals, suffered a deep transformation and became calxes. According to Stahl these common features were due to a component, which was present in all bodies and carried the property of combustibility. Stahl named this principle *phlogiston* (from the Greek φλογ, flame). The easier a body burned the more phlogiston it contained. During combustion phlogiston was released in the form of fire and dissipated in the air. The flame con-

tained the heat in pure and free form, while phlogiston constituted combined heat. Hence combustion was simply the transformation of combined fire to free fire.

An important property of phlogiston was that it could be transferred from one body to another by means of a chemical reaction. Thus, for example, when lead was heated it lost part of its phlogiston and became litharge, further heating led to the loss of the remaining phlogiston, the final product being minium.

The initial success of this theory was its being the first consistent theory that tried to explain chemical reactions in general and combustion in particular. Nevertheless, it had a basic defect: if phlogiston was a natural material (ponderable), its release by combustion should be accompanied by a decrease in weight and not by an increase, as actually observed. Many explanations were developed to explain this anomaly, for example, Macquer explained the increase in weight postulating that the metal first lost phlogiston (as in the classical theory), and then it combined with a quantity of air that exceeded the weight of the phlogiston lost. Macquer continued to affirm that combustion and calcinations released phlogiston and that it was the constitution matter of light. Exchange of phlogiston between two bodies gave place to substantial changes and it was this property that allowed distinguishing it from pure fire and to consider it as the fire element combined with another substance.¹⁰

In the beginning Fourcroy supported the phlogiston theory, for him a metal was formed by an unknown earth and phlogiston. During calcinations phlogiston left the metal and joined the air, part of which became saturated and unable to support further combustion, and part precipitated on the earth of the metal to generate the calx. Sulfur was composed of an unknown principle and phlogiston. On combustion phlogiston combined with part of the air to yield spent air, while the earth of sulfur united with the rest of the air to produce *acide vitriolique* (sulfuric acid). The decomposition of water by red-hot iron was explained by water being formed from an unknown principle and vital air; iron resulted from the union of a martial earth and phlogiston. The final result was iron calx and a flammable gas.

In the first edition of the notes for his chemistry course⁴ Fourcroy presented both the phlogiston and anti phlogiston theories, although he favored Macquer's opinion that during combustion and calcinations vital air was absorbed at the same time that phlogiston was released. He explicitly wrote that he did not reject or accept either of the two theories.

Eventually, the overwhelming amount of experimental data accumulated by Lavoisier led Fourcroy to reject the phlogiston theory and adopt the theory of pneumatic chemistry, which would lead to modern chemistry.¹¹ As mentioned by Smeaton³ this was an extremely important event because through the large public attending his course and his books Fourcroy became the lever that elevated Lavoisier's ideas to the front of chemistry.

2. Affinity

The causes of chemical combinations have always fascinated chemists. The concept of chemical affinity was introduced for the first time by Albert Le Grand in the sense it is attached to today: "*Le soufre noircit et brûle en général les métaux à cause de l'affinité naturelle qu'il a pour eux*" (Sulfur blackens and burns metals in general because of the affinity it has for them). Herman Boerhaave (1668-1738) attributed the combination to an especial force, which was the greater the more the two bodies were dissimilar. Chemists, initially, distinguished a certain number of affinities, affinity of aggregation, of composition, of dissolution, of decomposition, of precipitation, simple, double, or complicated. Louis-Bernard Guyton de Morveau (1737-1816) reduced them to five: aggregation, composition, prepared by cooperation (double), and affinity of excess. Initially Fourcroy distinguished only two types of affinity: by aggregation and by composition (chemical affinity) but in his *Système des Connaissances Chimiques*,¹² he adopted that of Guyton de Morveau. Fourcroy, noting that nitric acid and mercury combined with violence and formed a compound that decomposed easily, while hydrogen chloride yielded with difficulty a compound, which was unaffected by heat, proposed to measure affinity more by the difficulty of separating a compound into its principles than by the vivacity of their union. His first book⁹ already contains a tabu-

lar description of affinities. For example, the affinity of sulfuric acid towards *alkali fixe végétal* (potassium hydroxide) was 8 while towards *alkali volatil* (ammonium hydroxide) was 5. Since the sum of affinities between potassium nitrate and calcium sulfate was 13 and the sum of affinities between potassium sulfate and calcium nitrate was 12, then potassium sulfate was decomposed by calcium nitrate to yield potassium nitrate and calcium sulfate.

Fourcroy summarized his findings about affinity in the form of ten laws that regulated all phenomena based on affinity. For example, the attraction of composition took place only between bodies having different nature and in order to take place at least one of the bodies had to be fluid; the attraction of composition took place between the last molecules of the bodies, that is, the bodies had to be in a large state of division; when several bodies united or combined, their temperature changed and at the same time the attraction of combination changed between them; and that the attraction of composition was measured by the force that was necessary to apply in order to separate their constituents.

Eventually Claude-Louis Berthollet (1748-1822) would adopt a different position: affinities were not constant; they were variable and relative. If one wanted to predict the direction of a reaction he had also need to take into account other factors, such as insolubility, difference in solubility, volatility, fusibility, and the amounts of the reagents.¹³

3. Fourcroy's system

The most important treatise on chemistry known in the first decade of the nineteenth century was Fourcroy's *Système des Connaissances Chimiques*.¹² It had grown from a work originally encompassing two volumes in 1782 (*Leçons Élémentaires d'Histoire Naturelle et de Chimie* corresponding to the first set of notes for the chemistry course he started giving)⁴ to ten volumes in its final edition of 1800. The contents were divided into eight sections, each one preceded by an introductory discourse: (1) Bases of chemical science, generalities, and introduction, (2) Simple or undecomposed bodies, such as light, caloric, nitrogen oxygen, carbon, phosphorus, sulfur, and the metals, (3) Burnt bodies (*corps brûlés*), oxides, including water, and

acids, (4) Salifiable bases, earthy or alkaline, (5) Acids united to salifiable bases, or alkaline and earthy salts, (6) Metals in particular, (7) Organic vegetable compounds, and (8) Organic animal substances; this section contains a treatise on the chemical phenomena that characterize healthy and ill animals. Animal and vegetable chemistry were covered in four volumes and give us an insight into the state of organic chemical knowledge of the time.

Fourcroy's aims, as stated in the preface, were to collect more facts than were to be found in any previous work, and to present them as free as possible from the history, practice and applications of the subject, in a new order and with possible proofs and developments.

The section on the general composition of vegetables, entitled "Concerning the Succession of Labours and Discoveries relative to this Composition", starts with a historical summary of research on vegetable materials. At first sight, it would seem that the vegetable organization should form compounds completely different from those which constitute the fossils, and that the chemical phenomena that these compounds present should also be different. This conclusion was demonstrated by the experimental facts. One of the most astonishing findings had been the impossibility to restore vegetable substances to their original state after being altered by chemical operations. The analysis of mineral compounds yielded principles, which reunited or combined in the proportions given by the analysis, formed again the original compounds with all their properties.

Early researches dealt with the substances constituting organic tissues such as fats, starch, sugars, and fibrin, and were met by insurmountable obstacles in the handling of these materials; any violent action destroyed them yielding substances whose relation to the original material was far removed and impossible to determine.

To investigate the nature of these principles, and that of the entire vegetables, the violent action of fire by distillation in a retort, was adopted. It was believed that the principles obtained by distilling a material in a retort existed fully formed in the material and were solely separated by heat. This conception was so strong that the *Académie des Sciences* offered not

less than thirty prizes to the developers of methods for plant analysis by fire. A very conflicting fact was that the products obtained by distillation were similar, although derived from very different materials (for example, corn and hemlock). These discouraging results led chemists to try new separation methods, among them, extraction with solvents, which had the advantage of yielding the principles as they existed in the organism, without denaturation. Chemists began to treat plants with cold and hot water and with alcohol and to compare the different effects of these two solvents. The experiments led to considerable improvements in the extraction technique and to the discovery of new vegetable principles. For example, Claude Saint Mart de La Garaye (1675-1755) was instrumental in developing the extraction of soluble materials in finely ground vegetables, using cold water and mechanical agitation.

With the advent of pneumatic chemistry came the examination of the gas produced by fermentation and the proof of its identity with the gas produced from chalk. Afterwards Lavoisier examined the combustion products of several organic substances and found them to be fixed air and water. Since then, according to Fourcroy, progress had been steady.

In the third section about vegetables, entitled "On the Enumeration and Classification of the Immediate Materials of Vegetables", Fourcroy indicated that once chemists had succeeded in separating the different principles, the next question was how to relate the number and differences between them. Fourcroy began his treatment of the immediate principles of vegetables with a discussion of the possible systems of classification. Some chemists, for example Guillaume François Rouelle (1703-1770), used the mode of analysis as the criterion for classifying vegetable principles, that is, according to whether they were extracted by fire, solvents, etc. Others, such as Bucquet, used as a criterion the order of dissection of the plant, or a method based on systems of the vegetable. However, most chemists considered the principles from the viewpoint of medicinal preparation and followed a pharmaceutical order. Fourcroy felt that the above methods were not systematic and that the best method should be one

based on a comparison of the chemical properties of the principles. This method of arrangement not only depended on the chemical properties of the principles; it also led to the knowledge of their useful properties. He then listed twenty vegetable principles: sap, mucus matter, sugar, vegetable albumen, vegetable acids, extractive, tannin, starch, gluten, coloring matter, fixed oil, vegetable wax, volatile oil, camphor, resin, gum resin, balsam, rubber (caoutchouc), ligneous matter, and cork.

Fourcroy indicated that the first six principles of his list had the common property of being frequently dissolved in the water of the plant, of circulating with the sap, or could be dissolved in water. The following three had a pulverulent or lamellate form; the next ones, from fixed oil to rubber, were inflammable and insoluble in water and were present in particular cells or vessels of the plant. The last two formed the insoluble part of the plant, and constituted the common support and integument of all parts of the vegetable. Each of these principles was to be considered a particular genus of vegetable compounds to which species were to be referred.

An interesting (and curious) feature of Fourcroy's classification is the inclusion of true principles like camphor and starch along with complex mixtures like sap and extractive.

The following sections of the book are devoted to a more detailed description of the twenty principles, according to their source, methods of extraction, chemical properties, chemical products, species, and uses.

The section on vegetable acids, entitled "Of the Fourth of the Immediate Materials of Vegetables, or the Vegetable Acids", is the most extensively developed. Vegetable acids are subdivided into six classes (genera) depending on whether the acid is (1) found freely formed in plants (gallic, benzoic, fuccinic, malic, and citric), (2) found in salt form in plants (oxalate and tartrate), (3) produced by distillation (the pyrotartaric and pyroligneous acids), (4) prepared artificially and not found in nature (mucus, camphoric, and suberic acids), (5) prepared artificially and found in nature (malic, oxalic, and tartaric), and (6) a product of fermentation (acetous and acetic acids). The fifteen acids de-

scribed by Fourcroy were considered to be binary radicals of carbon and hydrogen united with oxygen and differing from the neutral vegetable oxides by their abundance of oxygen.

Fourcroy put animal chemistry after vegetable chemistry because it was more complicated and was the least advanced part of chemistry. He gave a brief history of animal chemistry with a summary of the analyses of urine, bile, silk, blood, hair, horn, albumen, and gelatin. All these substances contained nitrogen, and this fact distinguished them from vegetable matter. Similarly to vegetables, animal principles could be classified according to several criteria, for example, according to solubility, according to their physical state, according to whether they were excremental or secretional, and according to their chemical nature. Fourcroy indicated that one possibility was to classify the ninety-four known animal principles into eight classes depending on the abundance of one or other of its elements, as follows: (1) oily or hydrogenated substances such as fatty oils and bile, (2) oxides or oxygenated substances such as albumen, lymph, and cerebral pulp, (3) carbonated substances such as gelatin, mucus, membranes and the tendons, (4) nitrogenous substances such as muscle and certain visceral parenchymata, (5) acids, such as uric and formic, (6) salts, such as the aqueous and vitreous humour, tears, and saliva, (7) phosphates, such as nails, horns, hair and bone, and (8) mixed substances such as blood, milk, sperm, and urine. According to Fourcroy, the above system of classification would certainly be the most accurate if animal analyses were more advanced and if the comparative nature of the animal liquids and solids were better known. Since this was not the case, Fourcroy adopted a method, which was based on the actual state of chemistry and divided animal principles into three large categories: (1) those found in all animals and in all parts of the body, such as blood, lymph, fat, and cellular tissue, (2) those found in all animals but only in some region or organ, such as milk, nervous fluid, pulmonary concretions, nasal mucus, gastric juice, bile, chyle, urine, and sperm, and (3) those found only in some kinds of animals, such as feathers, ivory, wool, horn, eggs, fish oil, pearl, shells, cochineal, and coral.

Fourcroy developed the methods of immediate analysis and brought them to a fairly high degree of perfection. In his *Système* he described eight general methods of immediate analysis: (1) natural mechanical analysis, the spontaneous exudation of fluids to the outside, for example, sap, gums, manna, resins, and rubber, (2) artificial mechanical analysis, breaking of the cells or vessels with instruments in order to obtain plant juices, fixed oils, and essential oils, (3) analysis by distillation, to obtain products of different volatility, (4) analysis by combustion, (5) analysis by water, (6) analysis by acids and alkalis, (7) analysis by alcohol and water, and (8) analysis by fermentation.¹²

Connaissances chimiques contained too much detail for the beginner, for this reason Fourcroy published another book, *Tableaux Synoptiques de Chimie*,¹⁴ in which he gave succinct accounts of the individual substances, presented in tabular form so that the relation between them could be clearly seen.

The logical reform of the chemical language proposed by Lavoisier, Fourcroy, Berthollet, and Guyton de Morveau, did not gain a complete approval of the referees appointed by the *Académie des Sciences* in 1787, Antoine Baumé (1728-1804), Louis-Claude Cadet de Gassicourt (1731-1799), Darcet, and Balthazar-Georges Sage (1740-1824). The three were supporters of the phlogiston theory and hence they recommended: "*Nous pensons qu'il faut soumettre cette théorie nouvelle (la chimie pneumatique) ainsi que sa nomenclature, à l'épreuve du temps, au dire des expériences, au balancement des opinions qui en est la suivre; enfin au jugement du public comme au seul tribunal d'où elles doivent et puissent ressortir. Alors ce ne sera plus une théorie, cela deviendra un enchaînement de vérités, ou une erreur. Dans le premier cas, elle donnera une base solide de plus aux connaissances humaines, dans le second, elle rentrera dans l'oubli avec toutes les théories et les systèmes de physique qui l'ont précédé*" (We believe necessary to subject this new theory, as well as its nomenclature, to the test of time, to the experiments, to the doubts it has raised, in short, to the judgment of the public as the only tribunal. Then it will not be a theory; it will become a chain of facts or an error. In the first case it will provide a solid base for solid human knowledge; in the sec-

ond case, it will go into oblivion with all other theories and systems that have preceded it).

4. Fats and soaps

Carl Wilhelm Scheele's (1742-1786) discovery of glycerin did not change the usual manner of considering soap as consisting of the entire fat substance combined with potash or other metal bases. Glycerin was simply considered to be a sticky substance that appeared dissolved in certain oils and did not play a central role. According to Fourcroy,¹² when oil seeds were pressed the last fraction that separated was "*le mucilage gommeux...et souvent même il en reste une portion en véritable dissolution ou combinaison avec le suc huileux; c'est cette portion qui forme ce que Scheele a nommé le principe doux des huiles...C'est elle qui donne à la huile, quand on la brûle, les flacons épais qui la troublent et qui diminuent plus ou moins sa combustibilité*" (the gummy mucilage... part of which usually remains in solution with the oily juice; this is the portion that Scheele named the sweet principle of oils... It is the one that gives to the oil, when it is burned, the.... thick that... and that diminish, more or less, its flammability).

The invention of artificial soda was an important step toward the comprehension of the problem of saponification but full knowledge would have to wait until the discovery of the chemical nature of fats. Fourcroy⁴ believed in the existence of an "oily principle", which when combined with other substances, constituted the different kinds of fats found in vegetable nature. According to Fourcroy, an oil exposed to air became thickened little by little and became solid like tallow or wax due to a slow absorption of oxygen. Fats were only oils thickened by oxygen. Saponification also involved absorption of oxygen.

In 1780 and 1785 Berthollet published his results^{15,16} that provided the chemical background lacked by Macquer. He revealed the salt-like nature of soap by investigating the reaction between lime, water, and soap solution, removing the insoluble calcium salts by filtration and obtaining the caustic alkali by evaporation. According to Berthollet the reaction took place in two stages, first a double decomposition and then a double recomposition. The same results took place with salts of ammonia and salts of mag-

nesium, with calcium chloride and nitrate, mercury, cobalt, tin, copper, lead, silver, and gold. However, he attributed the formation of soap to the affinity of the oil for the alkali; they were compounds in which the base was neutralized by the entire fat, which action was analogous to that of an acid. Berthollet considered "*les savons comme des composés dans lesquels des bases salifiables étaient neutralisées par des matières grasses don't la action était analogue à celle des acides*" (soaps are compounds in which the salifiable basis are neutralized by fatty materials, the action been similar to that of acids).

During 1786 and 1787 the administration decided to transfer the *Cimetière des Innocents* (Cemetery of the Innocents), located in the center of Paris, which was full of corpses buried during three centuries and had become a serious health problem. The *Société Royale de Médecine* appointed a committee formed by Fourcroy and Michel-Augustin Thouret (1749-1810) to advise the police during the excavation and transfer of the bodies. During the disinterment process Fourcroy became familiar with a phenomenon that was well known to the gravediggers, that the flesh of certain corpses, particularly those buried in wet places, had transformed into a whitish grey soft substance, which became softer between the fingers. The gravediggers called this substance *gras de cadaver* (corpse fat). Fourcroy analysed the material and found that it was a kind of ammonia soap, essentially odourless, from which by acid treatment was possible to extract a white soft substance that softened more in contact with the hand. This solid also had properties analogous to wax and to the white solid in human urinary calculi. He concluded that almost all animal matter can be converted into this fat, which he called *adipocire* because it resembled both fat and wax.¹⁷⁻¹⁹ Fourcroy compared the new substance with spermaceti and the crystalline substance present in urinary calculi, and concluded incorrectly, that although the three had different melting points and solubility in alcohol, they corresponded to three varieties of *adipocire*.

Fourcroy used his findings to reject Berthollet's hypothesis and replace it by another where the formation of soap and plasters was due to the oxidation of oils under the in-

fluence of air and alkalis or metallic oxides. Vegetable butters, waxes, the solid fatty matter in a corpse, the one produced by a soap on decomposition by an acid, spermaceti, and cholesterin were grouped under the generic name of *adipocire* (fatty wax) and assumed to be a sort of fixed oil oxides (*d'oxydes d'huiles fixes*); they owed their generation to oxygen fixation by the oils. He regarded these substances as species of oxides of fixed oils. It would be left to Chevreul twenty-years later, to clear this point.²⁰

5. Urinary stones⁵

The composition of urinary stones and calculi had occupied scientists for many years. In 1776 Scheele discovered that the main component of a bladder stone was a substance that was slightly soluble in water and that the diluted solution colored litmus paper red. The matter melted in alkali and formed a precipitate in acid solution, which dissolved in a hot nitric acid leaving a residue, which after evaporation turned a pinkish crimson. Upon heating, and depending on the temperature, it smelled like prussic acid, ammonia, or something like burning horn.⁵ The acid was present in all urines, including that of infants. Scheele named the substance *lithic acid*; subsequently others changed the name to *uric acid*. Afterwards, Torbern Olof Bergman (1735-1784) confirmed Scheele's (1734-1794) findings. Scheele's results are important because they established that uric acid was a normal constituent of human urine and that when cold it produced brick-red sediment. Thus uric acid became the first metabolite to be identified in human urine, twenty years before Fourcroy and Vauquelin isolated urea in 1799.^{21,22} Since most stones contained uric acid Scheele reached the wrong conclusion that uric acid was the only constituent.

Afterwards, Vicq D'Azyr discussed all the animal secretions he had observed without discussing their possible chemical composition and concluded that uric acid urinary stones were due to hyperconcentration of the urine, because man urine always contained uric acid, regardless of the presence of calculi.²³

Fourcroy studied the relationship of bone disease to urinary stones, in particular the frequency of earthy stones (calcium salts) in rickets. He suspected that there was

an underlying abnormality of phosphoric acid metabolism because of its appearance in young children. In 1789 Fourcroy published his first results on the chemistry of gallstones²⁴ and stated that uric acid was rich in carbon and nitrogen but poor in oxygen and hydrogen. According to Fourcroy urinary stones contained uric acids and other substances such as calcium phosphate and magnesium ammonium phosphate; in addition, human renal and bladder stones had a similar composition.²⁵

In 1800 and 1802 Fourcroy and Vauquelin published two important memoirs on the composition of urinary calculi,^{26,27} obtained after analyzing over 600 calculi. In these memoirs they changed the name lithic acid to *acide urique* (uric acid). According to their results there were twelve main species of calculi, consisting of the following substances or mixtures of them: uric acid, ammonia urate, calcium phosphate, magnesium ammonium phosphate, calcium oxalate, and animal matter (gelatin). Uric acid was the commonest constituent. To explain the presence of calcium oxalate they proposed that oxalic acid was normally made somewhere within the walls of the urinary tract, and that it reacted with urine for form microscopic crystals of calcium oxalate. These crystals were usually very small and most of them were excreted as such. Nevertheless, some of them would become nucleation centers for calculi upon which other urinary salts were then deposited (An assumption known today to be true).⁵

Fourcroy and Vauquelin were surprised by the fact that phosphorus was present only as phosphate, in opposition to their findings on other substances such as living tissues, bone, and pollen. These findings may be considered the first indication that other chemical forms of phosphorus may have physiological functions. They also determined that the magnesium present came from the large amounts contained in cereals.

Fourcroy and Vauquelin considered that bezoar stones were composed of a kind of resin (probably ingested) in the case of those of the Persian wild goat; common bezoars consisted sometimes of calcium or magnesium phosphate, sometimes of resinous matter of bile. Analysis performed later by others proved that what Fourcroy and Vauquelin

had called *résine animale bézoardique* in bezoar stones was really derived from the resinous plants on which the wild goats feeds.^{5,27}

Fourcroy and Vauquelin also showed that fish-rope contains phosphorus²⁸ and that bones contain calcium and magnesium phosphates.²⁹

6. Miscellaneous

It was known that the precipitates of platinum chloride with ammonium or potassium chloride presented different colorations but these were not always yellow as expected. Fourcroy and Vauquelin investigated the residue left by the action of aqua regia on native platinum ore and found that it precipitated a red platinum chloride. From these results they concluded that it contained a new metal: "*Tout annonçait que le poudre noire contenait un metal nouveau* (Everything points out that the black powder contains a new metal).³⁰ Smithson Tennant (1761-1815) showed in 1804 that the residue actually contained two metals, osmium and iridium.³¹

Fourcroy and Vauquelin investigated the acid of ants and concluded incorrectly that it was a mixture of acetic acid and malic acid;³² they obtained benzoic acid by the action of hydrogen chloride on cow's or horse's urine or the drainage of manure, and proposed its use in pharmacy;³³ they investigated milk, cheese, blood, bile, etc.³⁴ and the coloring matter of blood, which they thought was iron phosphate with excess of oxygen and metal.³⁵

Vauquelin and Fourcroy discovered several important organic compounds. They distinguished a number of proximate constituents (*principes immédiats*) in plants, such as acids, oils, camphor, gum, resin, tannin, starch, fiber, cork, natural rubber, etc. Pyroligneous acid was shown by Vauquelin and Fourcroy to be impure acetic acid.

In order to try to solve the monetary deficit, the *Assemblée Nationale Constituante* decreed in 1789 that all the ecclesiastical property should be put at the disposition of the Nation; as a consequence many churches fell in disuse and a large number of bells came into the market and with them the interest in the large quantity of copper available in the form of bell metal, an alloy containing 20 to 25 % of tin. Several possibilities were considered for their use: to sell them as such, to separate the components, or to al-

loy them with a certain amount of copper in order to make them ductile enough so that they could be used to manufacture cannons, coins, or statues. Fourcroy's approach to the problem³⁶ was based on the variable affinity that oxygen has for metals. In a first set of experiments he studied the action of hot air on an artificial alloy of made of 80 % wt. copper and 20 % wt. tin. In a second series he used the metal of the bells and heated it in a crucible in the presence of air until the increase in weight showed that sufficient oxygen had been absorbed to convert all the tin into oxide. Analysis of the resulting product showed that the oxygen had actually combined with both metals. Consequently, he now heated the molten metal in a closed crucible, avoiding the possibility of further absorption of oxygen. During this second heating stage the copper oxide was reduced by the unreacted tin and after two to three hours the reaction was complete, all the tin was oxidized and could be separated from the molten copper. Crushed glass or marine salt were added in order to obtain refined copper and separate the tin oxide.

Fourcroy also tried to oxidize the tin by heating the alloy with certain metallic oxides; he achieved good separation with black oxide of manganese but litharge and oxide of arsenic were found to be unsatisfactory. In his final report he remarked that Bertrand. Pelletier (1761-1797) had also succeeded in separating the components with the aid of manganese oxide.

As a result, in 1793, when large quantities of copper were urgently needed for manufacturing cannon, the Committee of Public Safety decreed the destruction of all church bells. Instructions describing both Pelletier's and Fourcroy's methods were published in detail and both were recommended. Although Fourcroy's procedure was somewhat expensive it helped provide copper to the revolutionary government during the many wars it held during its existence.

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